Escola Tècnica Superior d'Enginyeries
Industrial i Aeronàutica de Terrassa
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Titulació:

Enginyeria en Organització Industrial

Alumne (nom i cognoms):

MARC DEIROS LLINÀS DEL TORRENT

Títol PFC:

Estudi de viabilitat d'una empresa de reforços de formigó amb materials compostos

Director del PFC:

Lluís Gil Espert

Convocatòria de lliurament del PFC:

JUNY 2013

Contingut d'aquest volum: **-ANNEXES-**

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UNIVERSITAT POLITÈCNICA DE CATALUNYA

Estudi de Viabilitat d'una Empresa de Reforços de Formigó amb Materials Compostos

ANNEXES

Autor: Marc Deiros Llinàs del Torrent

Tutor: Lluis Gil Espert

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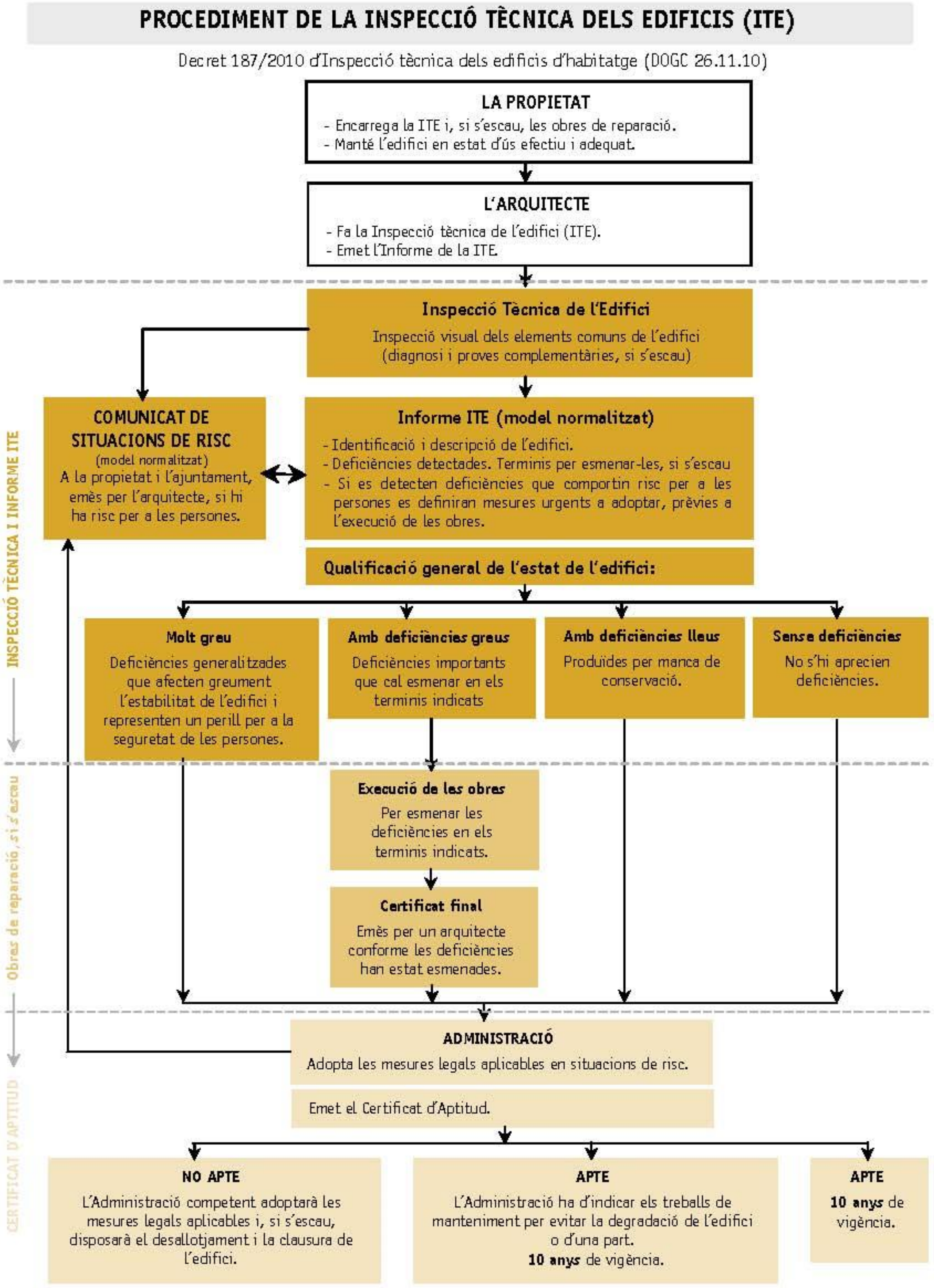
Juny 2013

ÍNDEX ANNEXES

ANNEX 1: INSPECCIÓ TÈCNICA D'EDIFICIS



PROCEDIMENT DE LA INSPECCIÓ TÈCNICA DELS EDIFICIS (ITE)

Decret 187/2010 d'Inspecció tècnica dels edificis d'habitatge (DOGC 26.11.10)

LA PROPIETAT
- Encarrega la ITE i, si s'escau, les obres de reparació.
- Manté l'edifici en estat d'ús efectiu i adequat.

L'ARQUITECTE
- Fa la Inspecció tècnica de l'edifici (ITE).
- Emet l'Informe de la ITE.

Inspecció Tècnica de l'Edifici
Inspecció visual dels elements comuns de l'edifici (diagnosi i proves complementàries, si s'escau)

COMUNICAT DE SITUACIONS DE RISC
(model normalitzat)
A la propietat i l'ajuntament, emès per l'arquitecte, si hi ha risc per a les persones.

Informe ITE (model normalitzat)
- Identificació i descripció de l'edifici.
- Deficiències detectades. Terminis per esmenar-les, si s'escau
- Si es detecten deficiències que comportin risc per a les persones es definiran mesures urgents a adoptar, prèvies a l'execució de les obres.

Qualificació general de l'estat de l'edifici:

Molt greu
Deficiències generalitzades que afecten greument l'estabilitat de l'edifici i representen un perill per a la seguretat de les persones.

Amb deficiències greus
Deficiències importants que cal esmenar en els terminis indicats

Amb deficiències lleus
Produïdes per manca de conservació.

Sense deficiències
No s'hi aprecien deficiències.

Execució de les obres
Per esmenar les deficiències en els terminis indicats.

Certificat final
Emès per un arquitecte conforme les deficiències han estat esmenades.

ADMINISTRACIÓ
Adopta les mesures legals aplicables en situacions de risc.

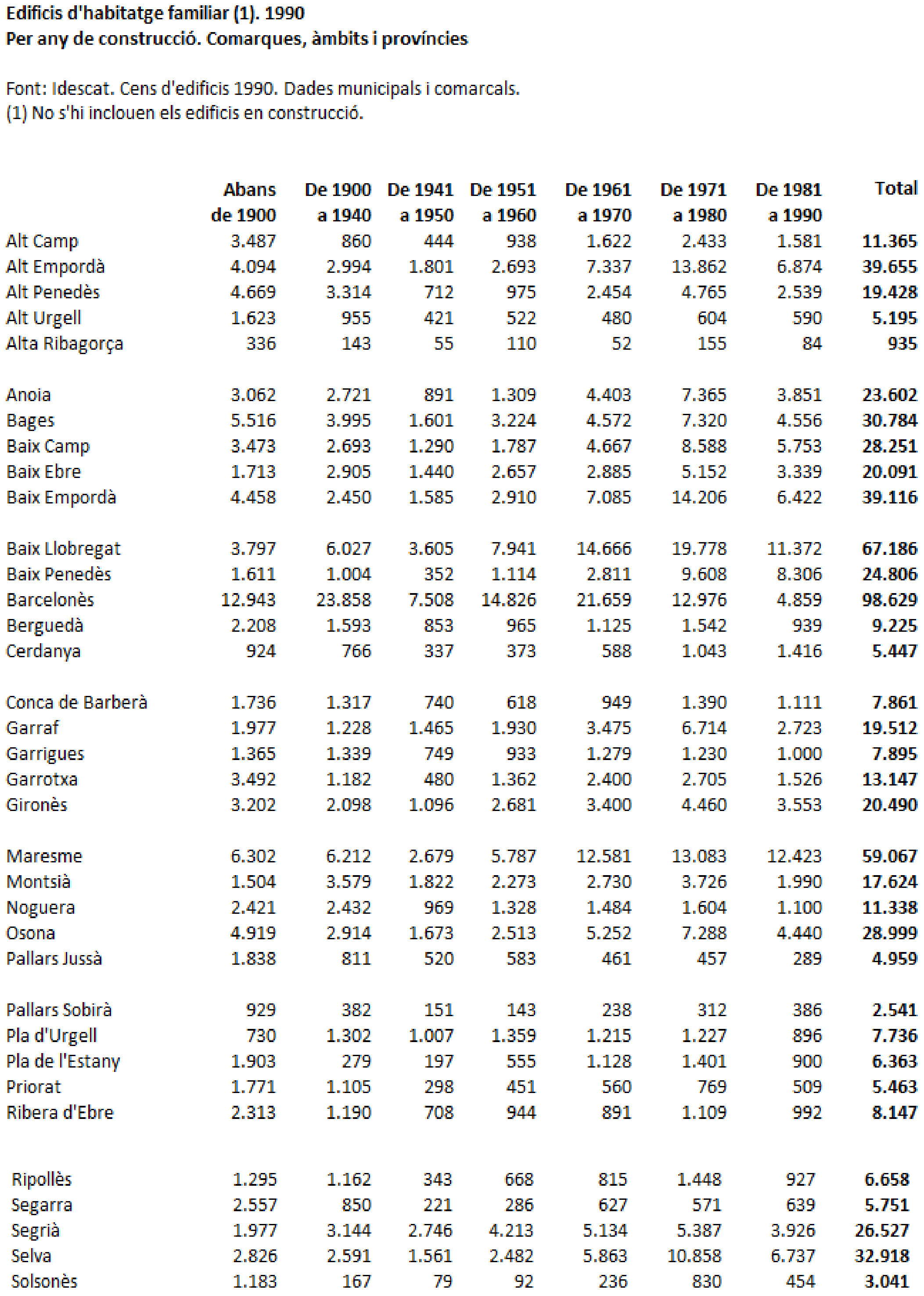
Emet el Certificat d'Aptitud.

NO APTE
L'Administració competent adoptarà les mesures legals aplicables i, si s'escau, disposarà el desallotjament i la clausura de l'edifici.

APTE
L'Administració ha d'indicar els treballs de manteniment per evitar la degradació de l'edifici o d'una part.
10 anys de vigència.

APTE
10 anys de vigència.

ANNEX 2: ESTADÍSTIQUES ANTIGUITAT EDIFICIS



Edificis d'habitatge familiar (1). 1990
Per any de construcció. Comarques, àmbits i províncies

Font: Idescat. Cens d'edificis 1990. Dades municipals i comarcals.
(1) No s'hi inclouen els edificis en construcció.

	Abans de 1900	De 1900 a 1940	De 1941 a 1950	De 1951 a 1960	De 1961 a 1970	De 1971 a 1980	De 1981 a 1990	Total
Alt Camp	3.487	860	444	938	1.622	2.433	1.581	**11.365**
Alt Empordà	4.094	2.994	1.801	2.693	7.337	13.862	6.874	**39.655**
Alt Penedès	4.669	3.314	712	975	2.454	4.765	2.539	**19.428**
Alt Urgell	1.623	955	421	522	480	604	590	**5.195**
Alta Ribagorça	336	143	55	110	52	155	84	**935**
Anoia	3.062	2.721	891	1.309	4.403	7.365	3.851	**23.602**
Bages	5.516	3.995	1.601	3.224	4.572	7.320	4.556	**30.784**
Baix Camp	3.473	2.693	1.290	1.787	4.667	8.588	5.753	**28.251**
Baix Ebre	1.713	2.905	1.440	2.657	2.885	5.152	3.339	**20.091**
Baix Empordà	4.458	2.450	1.585	2.910	7.085	14.206	6.422	**39.116**
Baix Llobregat	3.797	6.027	3.605	7.941	14.666	19.778	11.372	**67.186**
Baix Penedès	1.611	1.004	352	1.114	2.811	9.608	8.306	**24.806**
Barcelonès	12.943	23.858	7.508	14.826	21.659	12.976	4.859	**98.629**
Berguedà	2.208	1.593	853	965	1.125	1.542	939	**9.225**
Cerdanya	924	766	337	373	588	1.043	1.416	**5.447**
Conca de Barberà	1.736	1.317	740	618	949	1.390	1.111	**7.861**
Garraf	1.977	1.228	1.465	1.930	3.475	6.714	2.723	**19.512**
Garrigues	1.365	1.339	749	933	1.279	1.230	1.000	**7.895**
Garrotxa	3.492	1.182	480	1.362	2.400	2.705	1.526	**13.147**
Gironès	3.202	2.098	1.096	2.681	3.400	4.460	3.553	**20.490**
Maresme	6.302	6.212	2.679	5.787	12.581	13.083	12.423	**59.067**
Montsià	1.504	3.579	1.822	2.273	2.730	3.726	1.990	**17.624**
Noguera	2.421	2.432	969	1.328	1.484	1.604	1.100	**11.338**
Osona	4.919	2.914	1.673	2.513	5.252	7.288	4.440	**28.999**
Pallars Jussà	1.838	811	520	583	461	457	289	**4.959**
Pallars Sobirà	929	382	151	143	238	312	386	**2.541**
Pla d'Urgell	730	1.302	1.007	1.359	1.215	1.227	896	**7.736**
Pla de l'Estany	1.903	279	197	555	1.128	1.401	900	**6.363**
Priorat	1.771	1.105	298	451	560	769	509	**5.463**
Ribera d'Ebre	2.313	1.190	708	944	891	1.109	992	**8.147**
Ripollès	1.295	1.162	343	668	815	1.448	927	**6.658**
Segarra	2.557	850	221	286	627	571	639	**5.751**
Segrià	1.977	3.144	2.746	4.213	5.134	5.387	3.926	**26.527**
Selva	2.826	2.591	1.561	2.482	5.863	10.858	6.737	**32.918**
Solsonès	1.183	167	79	92	236	830	454	**3.041**

Tarragonès	2.592	2.193	757	1.756	5.898	8.366	6.202	**27.764**
Terra Alta	1.065	924	426	378	739	990	819	**5.341**
Urgell	2.706	1.544	854	706	1.138	1.390	995	**9.333**
Val d'Aran	461	292	163	199	215	758	782	**2.870**
Vallès Occidental	4.940	10.683	6.137	14.907	20.762	19.934	17.875	**95.238**
Vallès Oriental	3.237	6.354	2.741	5.122	10.369	15.863	10.525	**54.211**
Catalunya	**115.155**	**113.552**	**53.477**	**96.613**	**166.245**	**223.267**	**146.200**	**914.509**
Metropolità	37.865	57.676	24.847	51.488	85.966	93.113	62.316	**413.271**
Comarques Gironines	21.270	12.756	7.063	13.351	28.028	48.940	26.939	**158.347**
Camp de Tarragona	14.670	9.172	3.881	6.664	16.507	31.154	23.462	**105.510**
Terres de l'Ebre	6.595	8.598	4.396	6.252	7.245	10.977	7.140	**51.203**
Ponent	11.756	10.611	6.546	8.825	10.877	11.409	8.556	**68.580**
Comarques Centrals	16.888	11.390	5.097	8.103	15.588	24.345	14.240	**95.651**
Alt Pirineu i Aran	6.111	3.349	1.647	1.930	2.034	3.329	3.547	**21.947**
Barcelona	53.385	68.815	29.790	59.414	101.236	116.832	76.057	**505.529**
Girona	21.961	13.430	7.332	13.674	28.500	49.415	28.034	**162.346**
Lleida	18.544	13.537	8.078	10.609	12.757	14.889	11.507	**89.921**
Tarragona	21.265	17.770	8.277	12.916	23.752	42.131	30.602	**156.713**

Institut d'EstadÌstica de Catalunya
http://www.idescat.cat/pub/?id=aec&n=697&t=1990

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Barcelona	53.385	68.815	29.790	59.414	101.236	116.832	76.057	**505.529**
Girona	21.961	13.430	7.332	13.674	28.500	49.415	28.034	**162.346**
Lleida	18.544	13.537	8.078	10.609	12.757	14.889	11.507	**89.921**
Tarragona	21.265	17.770	8.277	12.916	23.752	42.131	30.602	**156.713**
Catalunya	**115.155**	**113.552**	**53.477**	**96.613**	**166.245**	**223.267**	**146.200**	**914.509**

ANNEX 3: REHABILITACIÓ A CATALUNYA

http://www.324.cat/noticia/1252326/economia/La-rehabilitacio-dedificis-salva-part-del-sector-de-la-construccio

Economia

Barcelona

La rehabilitació d'edificis salva part del sector de la construcció

Actualitzat a les 16:47 h 19/06/2011

Amb la crisi, la construcció és un dels sectors que ha frenat en sec i ha destruït més llocs de treball -es calcula que més d'un milió a tot l'Estat-. A curt termini, no hi ha perspectives que la construcció de nous habitatges torni a nivells d'abans de la crisi i, per això, el sector està mirant, un altre cop, cap a la rehabilitació. Una pràctica, que en anys de bonança, havia quedat pràcticament oblidada, però que ara -gràcies en part a l'augment de les desgravacions fiscals per als consumidors- està a punt de superar el nombre d'obres noves.

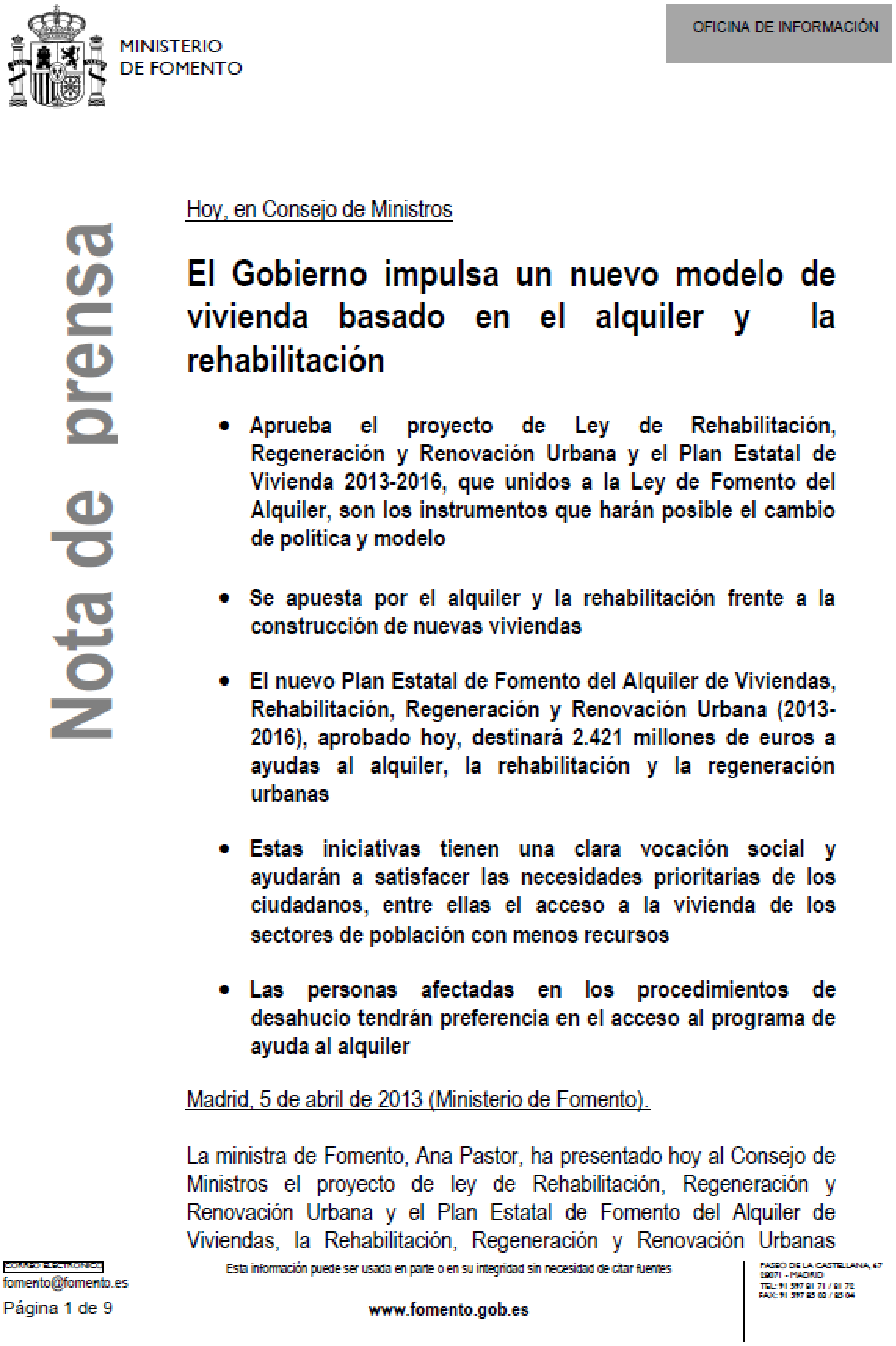
Això es pot veure en la davallada significativa de la construcció de nous habitatges. Si el primer trimestre del 2009, a Catalunya, es van acabar més de 10.000 pisos, el mateix període del 2011 se n'han acabat poc més de 4.000, cosa que significa una **caiguda de la construcció del 59%**.

El 2010, el nombre de reformes es va acostar al d'obres noves. I, si es manté la mateixa línia apuntada al primer trimestre d'aquest any, el 2011 pot tancar per primer cop amb **més reformes d'habitatges que edificis nous**.

La decisió del govern espanyol de **duplicar el tant per cent de desgravació** per a obres de rehabilitació, del 10% al 20%, és un primer pas, segons els professionals, per animar aquest mercat, però consideren que caldria complementar-ho amb altres mesures, com ara la baixada de l'IVA, que, a més, podria convertir-se en un incentiu perquè el **client demani factura** i **aflori l'economia submergida** que s'ha instal·lat en el castigat sector de la construcció.

Rehabilitar en comptes de construir

ANNEX 4: AJUDES REHABILITACIÓ ESPANYA



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Hoy, en Consejo de Ministros

El Gobierno impulsa un nuevo modelo de vivienda basado en el alquiler y la rehabilitación

- **Aprueba el proyecto de Ley de Rehabilitación, Regeneración y Renovación Urbana y el Plan Estatal de Vivienda 2013-2016, que unidos a la Ley de Fomento del Alquiler, son los instrumentos que harán posible el cambio de política y modelo**
- **Se apuesta por el alquiler y la rehabilitación frente a la construcción de nuevas viviendas**
- **El nuevo Plan Estatal de Fomento del Alquiler de Viviendas, Rehabilitación, Regeneración y Renovación Urbana (2013-2016), aprobado hoy, destinará 2.421 millones de euros a ayudas al alquiler, la rehabilitación y la regeneración urbanas**
- **Estas iniciativas tienen una clara vocación social y ayudarán a satisfacer las necesidades prioritarias de los ciudadanos, entre ellas el acceso a la vivienda de los sectores de población con menos recursos**
- **Las personas afectadas en los procedimientos de desahucio tendrán preferencia en el acceso al programa de ayuda al alquiler**

Madrid, 5 de abril de 2013 (Ministerio de Fomento).

La ministra de Fomento, Ana Pastor, ha presentado hoy al Consejo de Ministros el proyecto de ley de Rehabilitación, Regeneración y Renovación Urbana y el Plan Estatal de Fomento del Alquiler de Viviendas, la Rehabilitación, Regeneración y Renovación Urbanas

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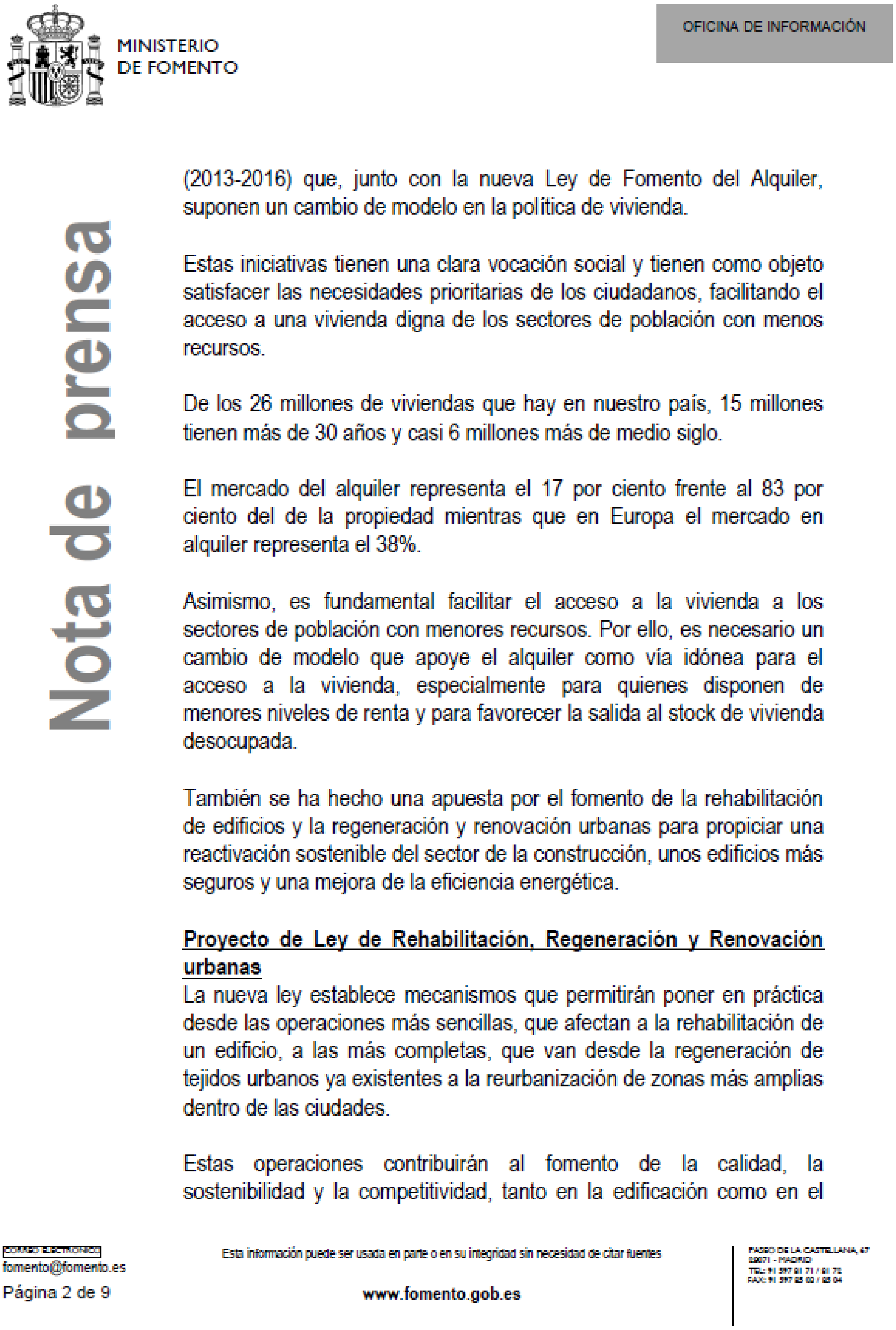

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(2013-2016) que, junto con la nueva Ley de Fomento del Alquiler, suponen un cambio de modelo en la política de vivienda.

Estas iniciativas tienen una clara vocación social y tienen como objeto satisfacer las necesidades prioritarias de los ciudadanos, facilitando el acceso a una vivienda digna de los sectores de población con menos recursos.

De los 26 millones de viviendas que hay en nuestro país, 15 millones tienen más de 30 años y casi 6 millones más de medio siglo.

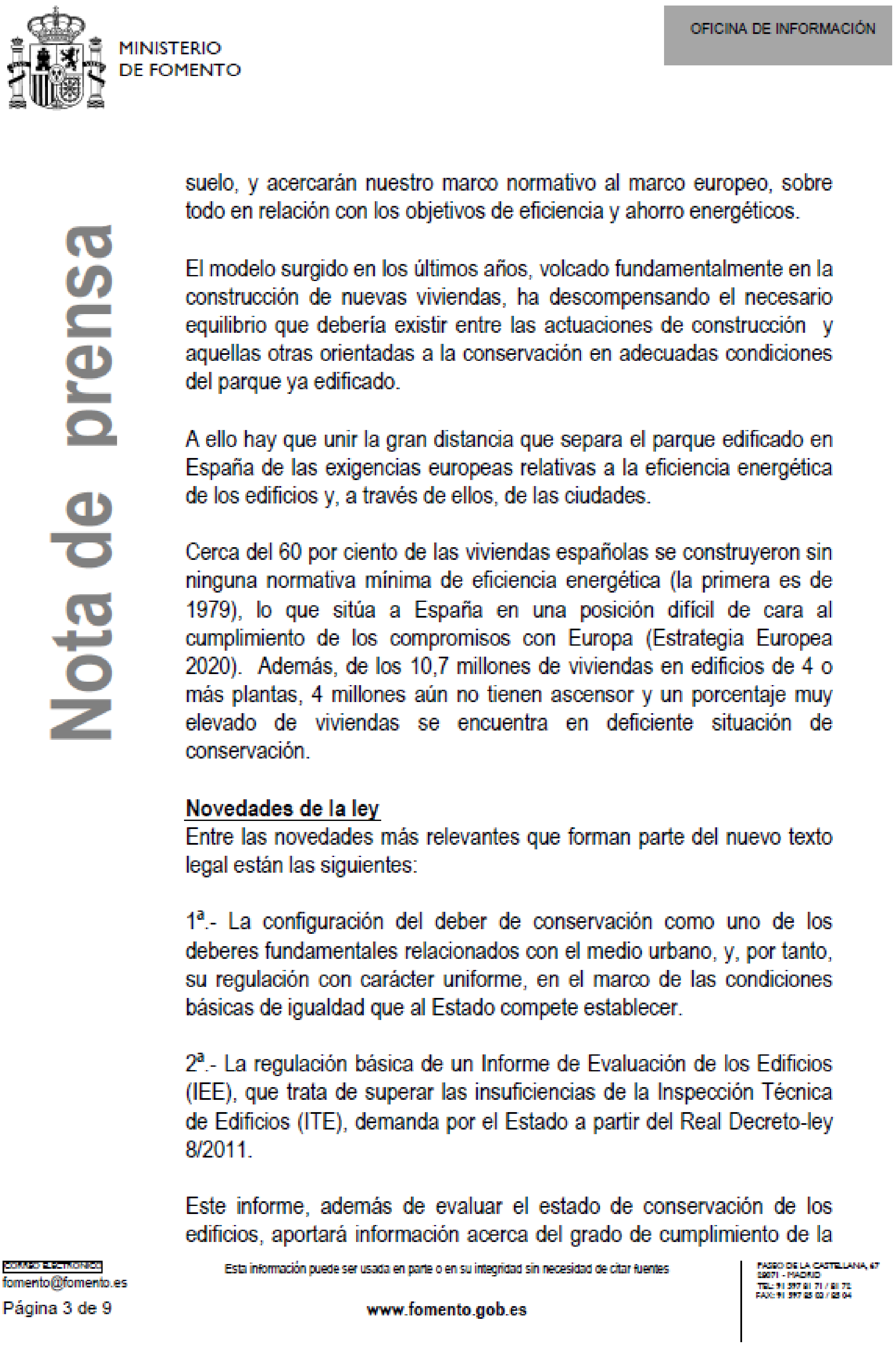
El mercado del alquiler representa el 17 por ciento frente al 83 por ciento del de la propiedad mientras que en Europa el mercado en alquiler representa el 38%.

Asimismo, es fundamental facilitar el acceso a la vivienda a los sectores de población con menores recursos. Por ello, es necesario un cambio de modelo que apoye el alquiler como vía idónea para el acceso a la vivienda, especialmente para quienes disponen de menores niveles de renta y para favorecer la salida al stock de vivienda desocupada.

También se ha hecho una apuesta por el fomento de la rehabilitación de edificios y la regeneración y renovación urbanas para propiciar una reactivación sostenible del sector de la construcción, unos edificios más seguros y una mejora de la eficiencia energética.

Proyecto de Ley de Rehabilitación, Regeneración y Renovación urbanas
La nueva ley establece mecanismos que permitirán poner en práctica desde las operaciones más sencillas, que afectan a la rehabilitación de un edificio, a las más completas, que van desde la regeneración de tejidos urbanos ya existentes a la reurbanización de zonas más amplias dentro de las ciudades.

Estas operaciones contribuirán al fomento de la calidad, la sostenibilidad y la competitividad, tanto en la edificación como en el



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suelo, y acercarán nuestro marco normativo al marco europeo, sobre todo en relación con los objetivos de eficiencia y ahorro energéticos.

El modelo surgido en los últimos años, volcado fundamentalmente en la construcción de nuevas viviendas, ha descompensando el necesario equilibrio que debería existir entre las actuaciones de construcción y aquellas otras orientadas a la conservación en adecuadas condiciones del parque ya edificado.

A ello hay que unir la gran distancia que separa el parque edificado en España de las exigencias europeas relativas a la eficiencia energética de los edificios y, a través de ellos, de las ciudades.

Cerca del 60 por ciento de las viviendas españolas se construyeron sin ninguna normativa mínima de eficiencia energética (la primera es de 1979), lo que sitúa a España en una posición difícil de cara al cumplimiento de los compromisos con Europa (Estrategia Europea 2020). Además, de los 10,7 millones de viviendas en edificios de 4 o más plantas, 4 millones aún no tienen ascensor y un porcentaje muy elevado de viviendas se encuentra en deficiente situación de conservación.

Novedades de la ley

Entre las novedades más relevantes que forman parte del nuevo texto legal están las siguientes:

1ª.- La configuración del deber de conservación como uno de los deberes fundamentales relacionados con el medio urbano, y, por tanto, su regulación con carácter uniforme, en el marco de las condiciones básicas de igualdad que al Estado compete establecer.

2ª.- La regulación básica de un Informe de Evaluación de los Edificios (IEE), que trata de superar las insuficiencias de la Inspección Técnica de Edificios (ITE), demanda por el Estado a partir del Real Decreto-ley 8/2011.

Este informe, además de evaluar el estado de conservación de los edificios, aportará información acerca del grado de cumplimiento de la

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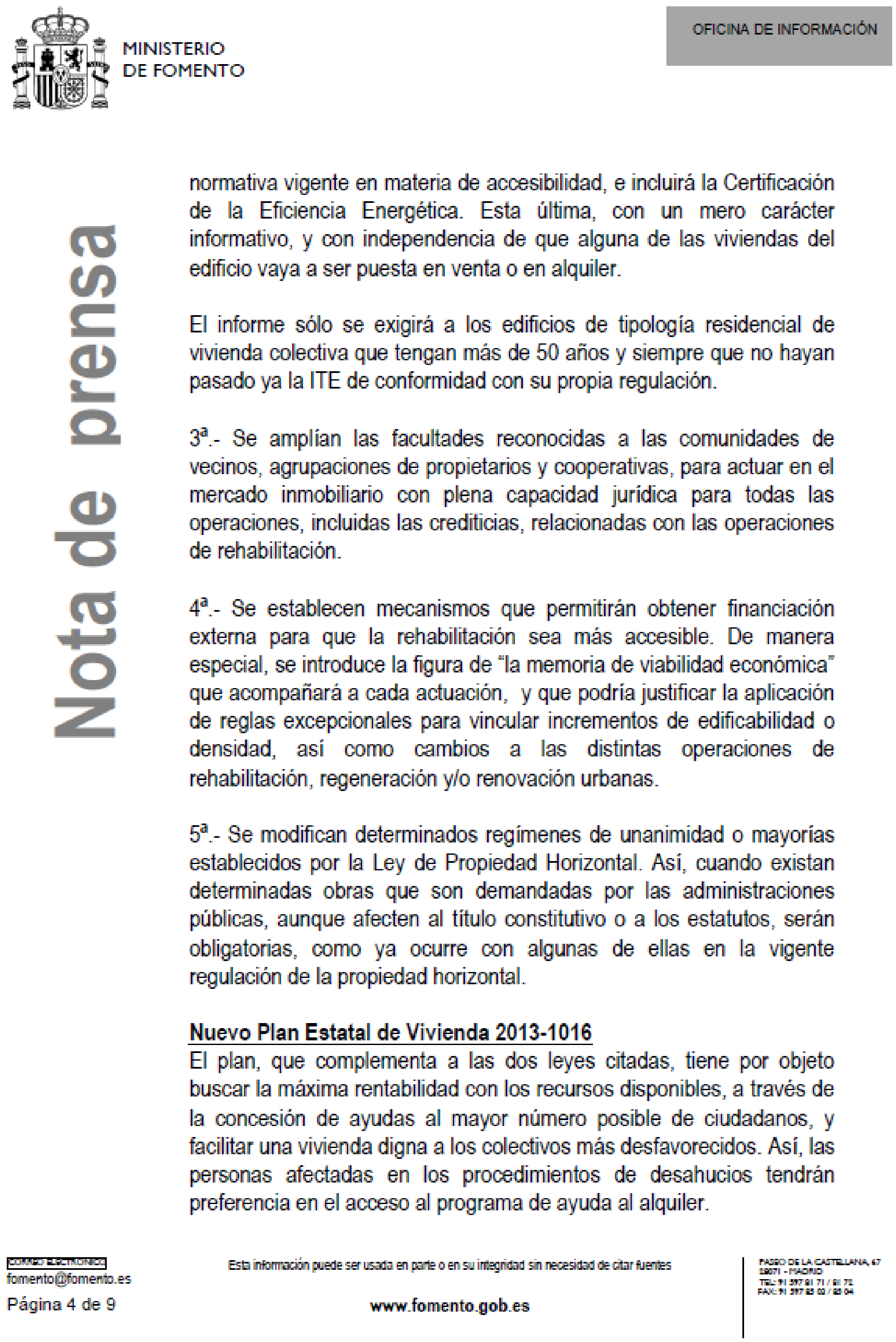

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normativa vigente en materia de accesibilidad, e incluirá la Certificación de la Eficiencia Energética. Esta última, con un mero carácter informativo, y con independencia de que alguna de las viviendas del edificio vaya a ser puesta en venta o en alquiler.

El informe sólo se exigirá a los edificios de tipología residencial de vivienda colectiva que tengan más de 50 años y siempre que no hayan pasado ya la ITE de conformidad con su propia regulación.

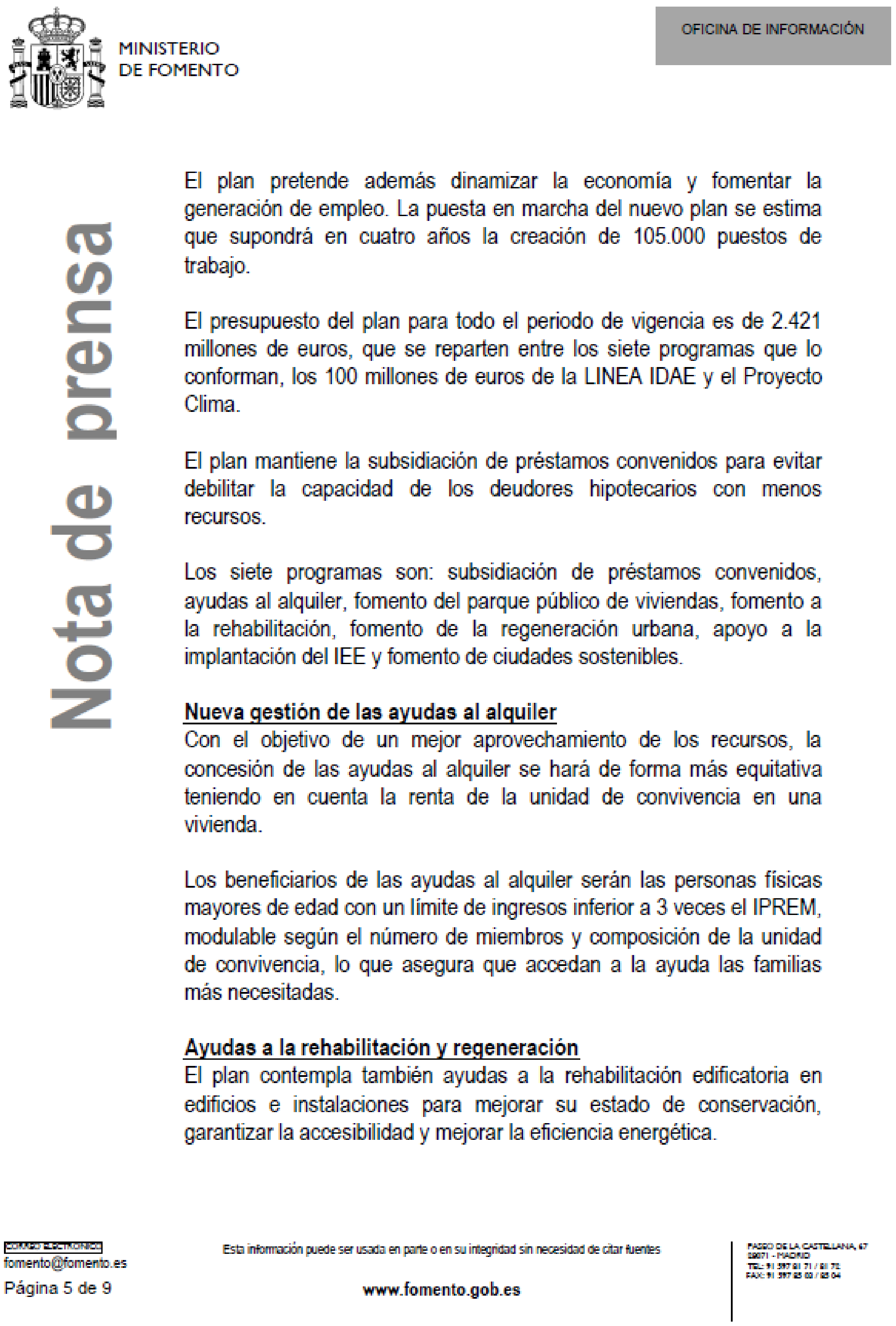
3ª.- Se amplían las facultades reconocidas a las comunidades de vecinos, agrupaciones de propietarios y cooperativas, para actuar en el mercado inmobiliario con plena capacidad jurídica para todas las operaciones, incluidas las crediticias, relacionadas con las operaciones de rehabilitación.

4ª.- Se establecen mecanismos que permitirán obtener financiación externa para que la rehabilitación sea más accesible. De manera especial, se introduce la figura de "la memoria de viabilidad económica" que acompañará a cada actuación, y que podría justificar la aplicación de reglas excepcionales para vincular incrementos de edificabilidad o densidad, así como cambios a las distintas operaciones de rehabilitación, regeneración y/o renovación urbanas.

5ª.- Se modifican determinados regímenes de unanimidad o mayorías establecidos por la Ley de Propiedad Horizontal. Así, cuando existan determinadas obras que son demandadas por las administraciones públicas, aunque afecten al título constitutivo o a los estatutos, serán obligatorias, como ya ocurre con algunas de ellas en la vigente regulación de la propiedad horizontal.

Nuevo Plan Estatal de Vivienda 2013-1016

El plan, que complementa a las dos leyes citadas, tiene por objeto buscar la máxima rentabilidad con los recursos disponibles, a través de la concesión de ayudas al mayor número posible de ciudadanos, y facilitar una vivienda digna a los colectivos más desfavorecidos. Así, las personas afectadas en los procedimientos de desahucios tendrán preferencia en el acceso al programa de ayuda al alquiler.



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El plan pretende además dinamizar la economía y fomentar la generación de empleo. La puesta en marcha del nuevo plan se estima que supondrá en cuatro años la creación de 105.000 puestos de trabajo.

El presupuesto del plan para todo el periodo de vigencia es de 2.421 millones de euros, que se reparten entre los siete programas que lo conforman, los 100 millones de euros de la LINEA IDAE y el Proyecto Clima.

El plan mantiene la subsidiación de préstamos convenidos para evitar debilitar la capacidad de los deudores hipotecarios con menos recursos.

Los siete programas son: subsidiación de préstamos convenidos, ayudas al alquiler, fomento del parque público de viviendas, fomento a la rehabilitación, fomento de la regeneración urbana, apoyo a la implantación del IEE y fomento de ciudades sostenibles.

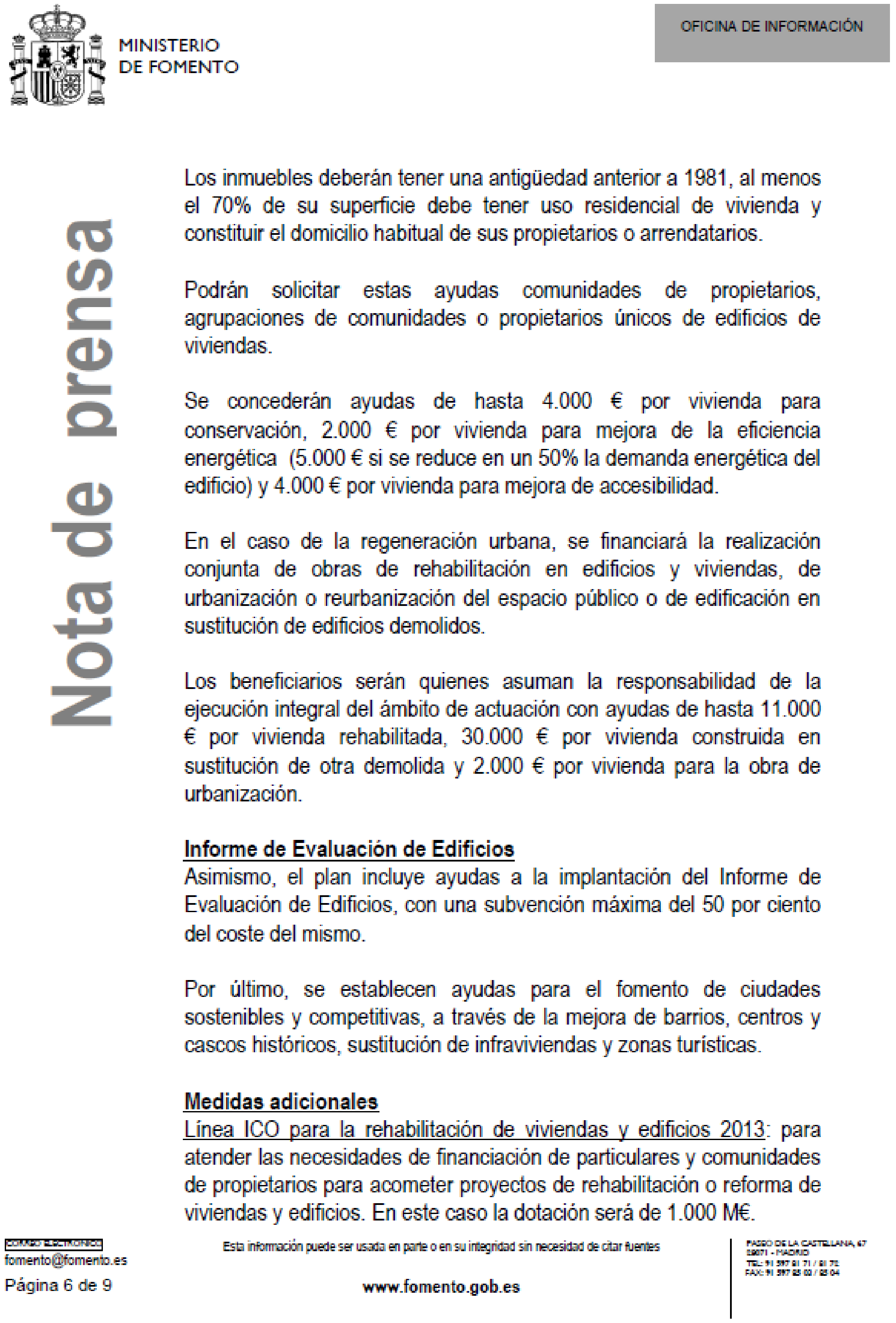
Nueva gestión de las ayudas al alquiler

Con el objetivo de un mejor aprovechamiento de los recursos, la concesión de las ayudas al alquiler se hará de forma más equitativa teniendo en cuenta la renta de la unidad de convivencia en una vivienda.

Los beneficiarios de las ayudas al alquiler serán las personas físicas mayores de edad con un límite de ingresos inferior a 3 veces el IPREM, modulable según el número de miembros y composición de la unidad de convivencia, lo que asegura que accedan a la ayuda las familias más necesitadas.

Ayudas a la rehabilitación y regeneración

El plan contempla también ayudas a la rehabilitación edificatoria en edificios e instalaciones para mejorar su estado de conservación, garantizar la accesibilidad y mejorar la eficiencia energética.



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Los inmuebles deberán tener una antigüedad anterior a 1981, al menos el 70% de su superficie debe tener uso residencial de vivienda y constituir el domicilio habitual de sus propietarios o arrendatarios.

Podrán solicitar estas ayudas comunidades de propietarios, agrupaciones de comunidades o propietarios únicos de edificios de viviendas.

Se concederán ayudas de hasta 4.000 € por vivienda para conservación, 2.000 € por vivienda para mejora de la eficiencia energética (5.000 € si se reduce en un 50% la demanda energética del edificio) y 4.000 € por vivienda para mejora de accesibilidad.

En el caso de la regeneración urbana, se financiará la realización conjunta de obras de rehabilitación en edificios y viviendas, de urbanización o reurbanización del espacio público o de edificación en sustitución de edificios demolidos.

Los beneficiarios serán quienes asuman la responsabilidad de la ejecución integral del ámbito de actuación con ayudas de hasta 11.000 € por vivienda rehabilitada, 30.000 € por vivienda construida en sustitución de otra demolida y 2.000 € por vivienda para la obra de urbanización.

Informe de Evaluación de Edificios

Asimismo, el plan incluye ayudas a la implantación del Informe de Evaluación de Edificios, con una subvención máxima del 50 por ciento del coste del mismo.

Por último, se establecen ayudas para el fomento de ciudades sostenibles y competitivas, a través de la mejora de barrios, centros y cascos históricos, sustitución de infraviviendas y zonas turísticas.

Medidas adicionales

Línea ICO para la rehabilitación de viviendas y edificios 2013: para atender las necesidades de financiación de particulares y comunidades de propietarios para acometer proyectos de rehabilitación o reforma de viviendas y edificios. En este caso la dotación será de 1.000 M€.

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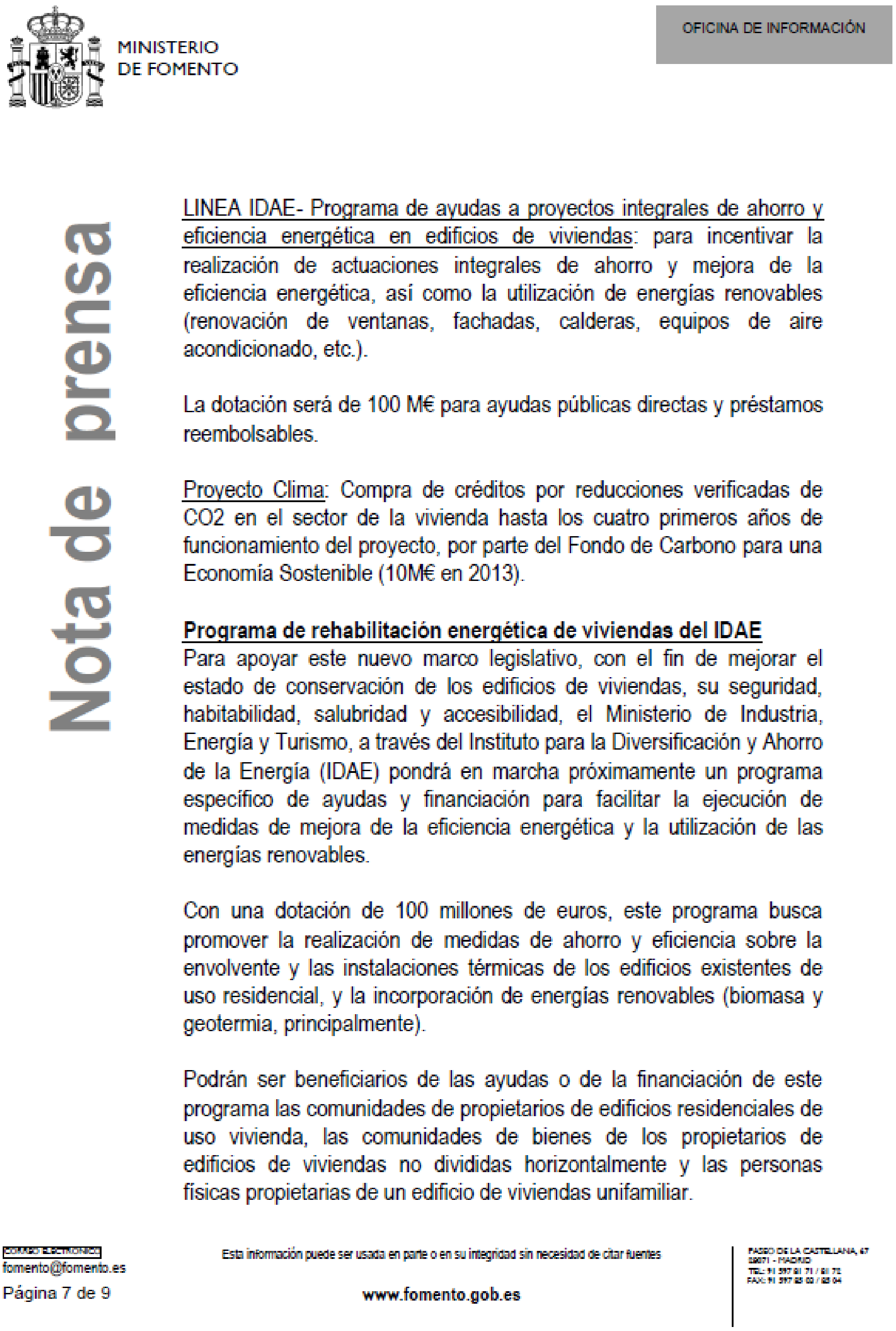

MINISTERIO
DE FOMENTO

OFICINA DE INFORMACIÓN

Nota de prensa

LINEA IDAE- Programa de ayudas a proyectos integrales de ahorro y eficiencia energética en edificios de viviendas: para incentivar la realización de actuaciones integrales de ahorro y mejora de la eficiencia energética, así como la utilización de energías renovables (renovación de ventanas, fachadas, calderas, equipos de aire acondicionado, etc.).

La dotación será de 100 M€ para ayudas públicas directas y préstamos reembolsables.

Proyecto Clima: Compra de créditos por reducciones verificadas de CO2 en el sector de la vivienda hasta los cuatro primeros años de funcionamiento del proyecto, por parte del Fondo de Carbono para una Economía Sostenible (10M€ en 2013).

Programa de rehabilitación energética de viviendas del IDAE

Para apoyar este nuevo marco legislativo, con el fin de mejorar el estado de conservación de los edificios de viviendas, su seguridad, habitabilidad, salubridad y accesibilidad, el Ministerio de Industria, Energía y Turismo, a través del Instituto para la Diversificación y Ahorro de la Energía (IDAE) pondrá en marcha próximamente un programa específico de ayudas y financiación para facilitar la ejecución de medidas de mejora de la eficiencia energética y la utilización de las energías renovables.

Con una dotación de 100 millones de euros, este programa busca promover la realización de medidas de ahorro y eficiencia sobre la envolvente y las instalaciones térmicas de los edificios existentes de uso residencial, y la incorporación de energías renovables (biomasa y geotermia, principalmente).

Podrán ser beneficiarios de las ayudas o de la financiación de este programa las comunidades de propietarios de edificios residenciales de uso vivienda, las comunidades de bienes de los propietarios de edificios de viviendas no divididas horizontalmente y las personas físicas propietarias de un edificio de viviendas unifamiliar.

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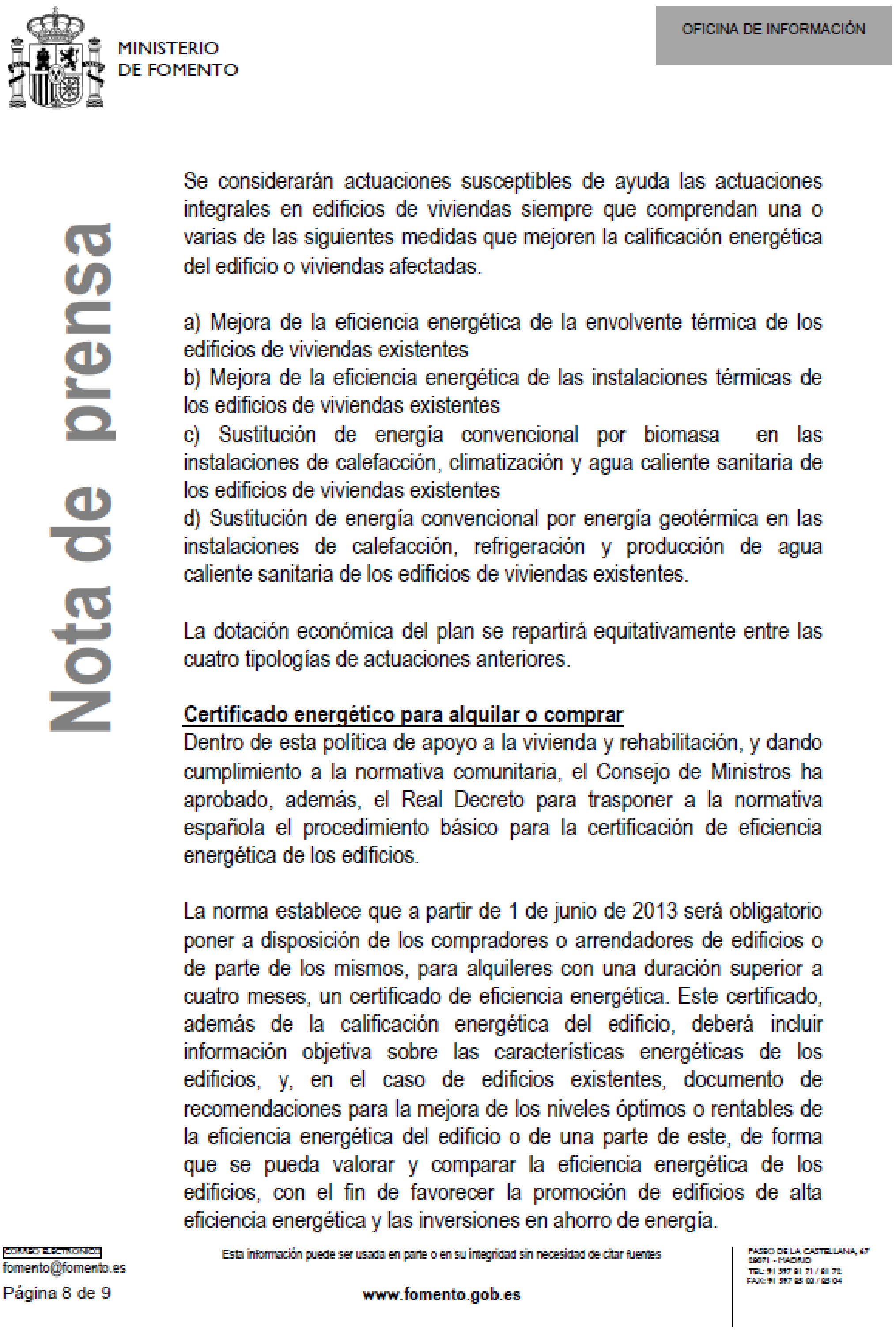

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Nota de prensa

Se considerarán actuaciones susceptibles de ayuda las actuaciones integrales en edificios de viviendas siempre que comprendan una o varias de las siguientes medidas que mejoren la calificación energética del edificio o viviendas afectadas.

a) Mejora de la eficiencia energética de la envolvente térmica de los edificios de viviendas existentes
b) Mejora de la eficiencia energética de las instalaciones térmicas de los edificios de viviendas existentes
c) Sustitución de energía convencional por biomasa en las instalaciones de calefacción, climatización y agua caliente sanitaria de los edificios de viviendas existentes
d) Sustitución de energía convencional por energía geotérmica en las instalaciones de calefacción, refrigeración y producción de agua caliente sanitaria de los edificios de viviendas existentes.

La dotación económica del plan se repartirá equitativamente entre las cuatro tipologías de actuaciones anteriores.

Certificado energético para alquilar o comprar
Dentro de esta política de apoyo a la vivienda y rehabilitación, y dando cumplimiento a la normativa comunitaria, el Consejo de Ministros ha aprobado, además, el Real Decreto para trasponer a la normativa española el procedimiento básico para la certificación de eficiencia energética de los edificios.

La norma establece que a partir de 1 de junio de 2013 será obligatorio poner a disposición de los compradores o arrendadores de edificios o de parte de los mismos, para alquileres con una duración superior a cuatro meses, un certificado de eficiencia energética. Este certificado, además de la calificación energética del edificio, deberá incluir información objetiva sobre las características energéticas de los edificios, y, en el caso de edificios existentes, documento de recomendaciones para la mejora de los niveles óptimos o rentables de la eficiencia energética del edificio o de una parte de este, de forma que se pueda valorar y comparar la eficiencia energética de los edificios, con el fin de favorecer la promoción de edificios de alta eficiencia energética y las inversiones en ahorro de energía.

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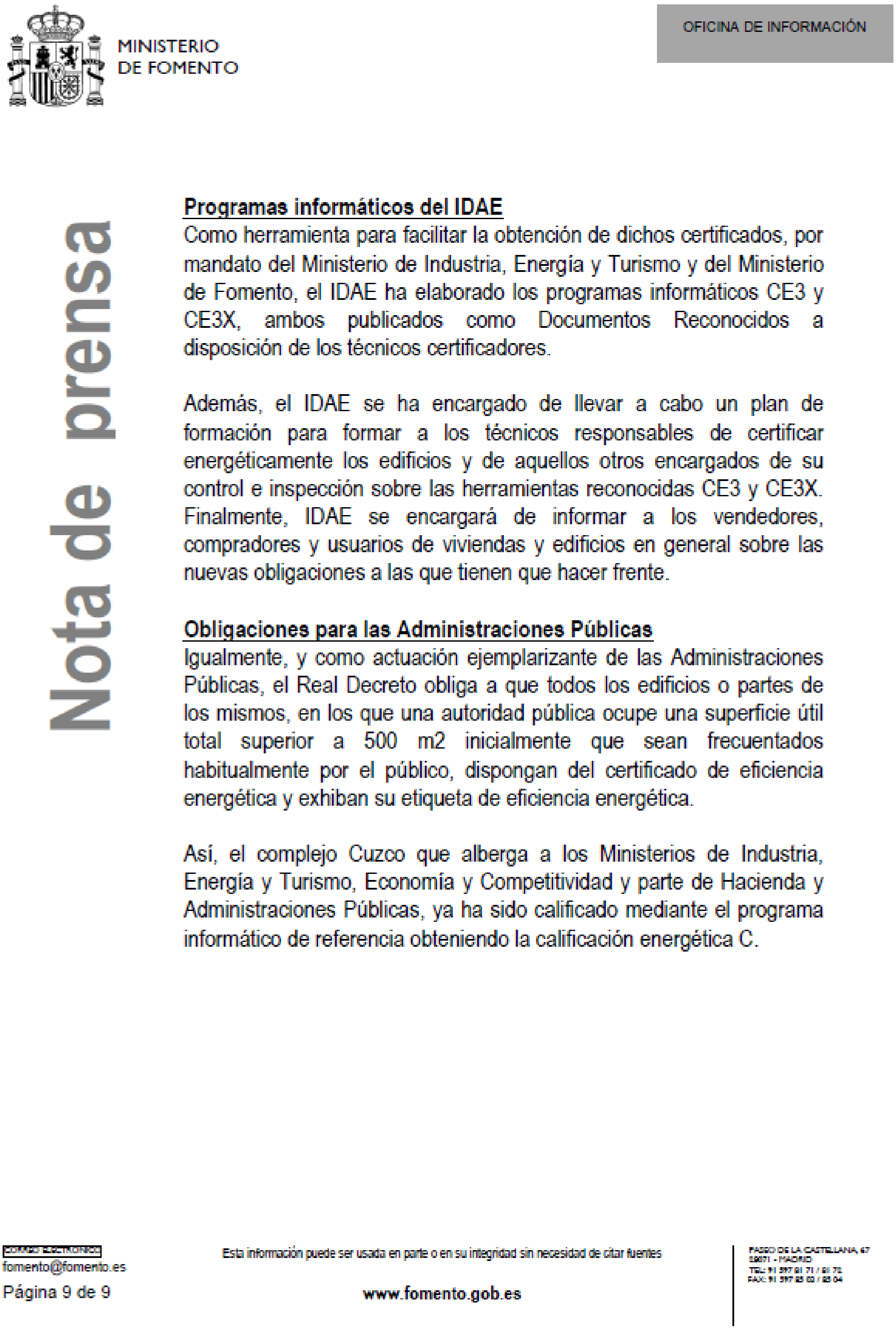

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Programas informáticos del IDAE

Como herramienta para facilitar la obtención de dichos certificados, por mandato del Ministerio de Industria, Energía y Turismo y del Ministerio de Fomento, el IDAE ha elaborado los programas informáticos CE3 y CE3X, ambos publicados como Documentos Reconocidos a disposición de los técnicos certificadores.

Además, el IDAE se ha encargado de llevar a cabo un plan de formación para formar a los técnicos responsables de certificar energéticamente los edificios y de aquellos otros encargados de su control e inspección sobre las herramientas reconocidas CE3 y CE3X. Finalmente, IDAE se encargará de informar a los vendedores, compradores y usuarios de viviendas y edificios en general sobre las nuevas obligaciones a las que tienen que hacer frente.

Obligaciones para las Administraciones Públicas

Igualmente, y como actuación ejemplarizante de las Administraciones Públicas, el Real Decreto obliga a que todos los edificios o partes de los mismos, en los que una autoridad pública ocupe una superficie útil total superior a 500 m2 inicialmente que sean frecuentados habitualmente por el público, dispongan del certificado de eficiencia energética y exhiban su etiqueta de eficiencia energética.

Así, el complejo Cuzco que alberga a los Ministerios de Industria, Energía y Turismo, Economía y Competitividad y parte de Hacienda y Administraciones Públicas, ya ha sido calificado mediante el programa informático de referencia obteniendo la calificación energética C.

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ANNEX 5: ARTICLE "EL MUNDO" NOU PLA

http://www.elmundo.es/elmundo/2012/12/19/suvivienda/1355922963.html

POLÍTICA | Conferencia Sectorial con las comunidades autónomas

El nuevo Plan Estatal de Vivienda estará en marcha antes de abril de 2013

El secretario de Estado de Infraestructuras y la directora general de Arquitectura. | Efe.

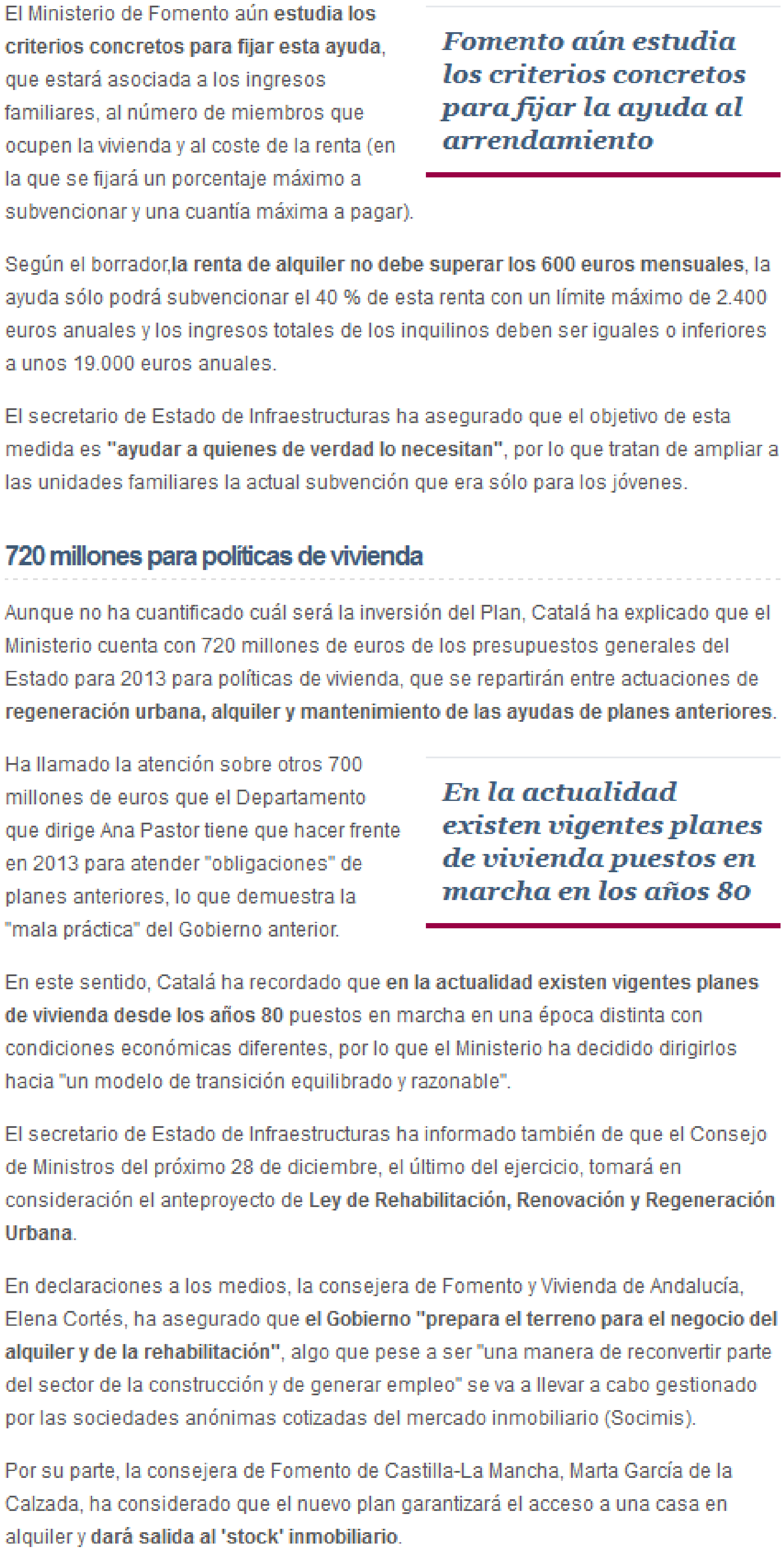
- **El objetivo es que el sector no siga orientado a la edificación de vivienda**
- **Destinará la mayor parte de sus recursos al alquiler y a la rehabilitación**
- **Fomento presentará la reforma de la rehabilitación el 28 de diciembre**
- **Se contemplarán ayudas para mejorar problemas de accesibilidad y eficiencia**

Efe | Madrid

Actualizado miércoles 19/12/2012 **14:18 horas**

El nuevo Plan Estatal de Vivienda 2013-2016 que prepara el Ministerio de Fomento comenzará a aplicarse durante el primer trimestre del próximo año, después de que sea aprobado por Decreto Ley a principios de febrero, según ha explicado el secretario de Estado de Infraestructuras, Rafael Catalá.

Tras la Conferencia Sectorial de Vivienda, el secretario de Estado de Infraestructuras ha explicado que el Ministerio **sigue trabajando con el borrador de este plan** que destinará la mayor parte de sus recursos a ayudas al alquiler en función de la renta y a la rehabilitación de edificios, viviendas y barrios.



El Ministerio de Fomento aún **estudia los criterios concretos para fijar esta ayuda**, que estará asociada a los ingresos familiares, al número de miembros que ocupen la vivienda y al coste de la renta (en la que se fijará un porcentaje máximo a subvencionar y una cuantía máxima a pagar).

> ***Fomento aún estudia los criterios concretos para fijar la ayuda al arrendamiento***

Según el borrador,**la renta de alquiler no debe superar los 600 euros mensuales**, la ayuda sólo podrá subvencionar el 40 % de esta renta con un límite máximo de 2.400 euros anuales y los ingresos totales de los inquilinos deben ser iguales o inferiores a unos 19.000 euros anuales.

El secretario de Estado de Infraestructuras ha asegurado que el objetivo de esta medida es **"ayudar a quienes de verdad lo necesitan"**, por lo que tratan de ampliar a las unidades familiares la actual subvención que era sólo para los jóvenes.

720 millones para políticas de vivienda

Aunque no ha cuantificado cuál será la inversión del Plan, Catalá ha explicado que el Ministerio cuenta con 720 millones de euros de los presupuestos generales del Estado para 2013 para políticas de vivienda, que se repartirán entre actuaciones de **regeneración urbana, alquiler y mantenimiento de las ayudas de planes anteriores**.

Ha llamado la atención sobre otros 700 millones de euros que el Departamento que dirige Ana Pastor tiene que hacer frente en 2013 para atender "obligaciones" de planes anteriores, lo que demuestra la "mala práctica" del Gobierno anterior.

> ***En la actualidad existen vigentes planes de vivienda puestos en marcha en los años 80***

En este sentido, Catalá ha recordado que **en la actualidad existen vigentes planes de vivienda desde los años 80** puestos en marcha en una época distinta con condiciones económicas diferentes, por lo que el Ministerio ha decidido dirigirlos hacia "un modelo de transición equilibrado y razonable".

El secretario de Estado de Infraestructuras ha informado también de que el Consejo de Ministros del próximo 28 de diciembre, el último del ejercicio, tomará en consideración el anteproyecto de **Ley de Rehabilitación, Renovación y Regeneración Urbana**.

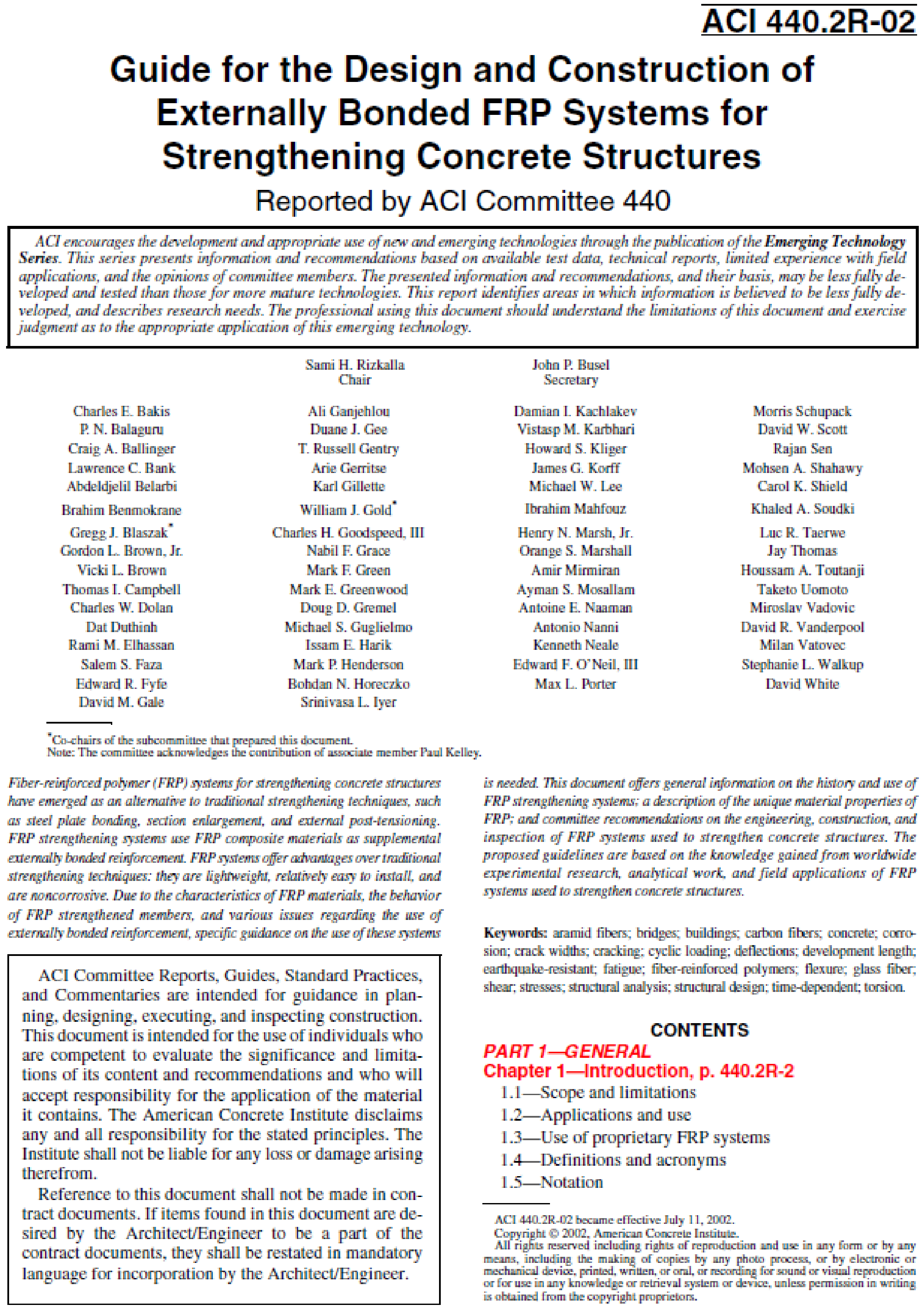
En declaraciones a los medios, la consejera de Fomento y Vivienda de Andalucía, Elena Cortés, ha asegurado que **el Gobierno "prepara el terreno para el negocio del alquiler y de la rehabilitación"**, algo que pese a ser "una manera de reconvertir parte del sector de la construcción y de generar empleo" se va a llevar a cabo gestionado por las sociedades anónimas cotizadas del mercado inmobiliario (Socimis).

Por su parte, la consejera de Fomento de Castilla-La Mancha, Marta García de la Calzada, ha considerado que el nuevo plan garantizará el acceso a una casa en alquiler y **dará salida al 'stock' inmobiliario**.

ANNEX 6: COMPARACIÓ CFRP - ACER

Característiques	**CFRP**	**Acer**
Elasticitat	Alta	Baixa
Fatiga Material	Després de arribar al **90%** de la resistència a la tracció	Després de arribar al **50%** de la resistència a la tracció
Oxidació	No	Si
Expansió Tèrmica	No	Si
Estètica	No hi ha canvis en l'estructura original	Hi ha canvis en l'estructura original
Resistència a la Tracció	Alta	Baixa
Pes Material	Lleuger	Pesat
Temps Aplicació	Curt	Llarg
Brutícia	Baixa	Alta
Manteniment Futur	No requereix	Requereix
Durabilitat	Alta	Baixa
Costos Aplicació	Baixos	40-50% més
Eines	Poques i lleugeres	Moltes i pesades

ANNEX 7: ACI 440.2R-02



ACI 440.2R-02

Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

Reported by ACI Committee 440

ACI encourages the development and appropriate use of new and emerging technologies through the publication of the ***Emerging Technology Series****. This series presents information and recommendations based on available test data, technical reports, limited experience with field applications, and the opinions of committee members. The presented information and recommendations, and their basis, may be less fully developed and tested than those for more mature technologies. This report identifies areas in which information is believed to be less fully developed, and describes research needs. The professional using this document should understand the limitations of this document and exercise judgment as to the appropriate application of this emerging technology.*

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Chair

John P. Busel
Secretary

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David White

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*Co-chairs of the subcommittee that prepared this document.
Note: The committee acknowledges the contribution of associate member Paul Kelley.

Fiber-reinforced polymer (FRP) systems for strengthening concrete structures have emerged as an alternative to traditional strengthening techniques, such as steel plate bonding, section enlargement, and external post-tensioning. FRP strengthening systems use FRP composite materials as supplemental externally bonded reinforcement. FRP systems offer advantages over traditional strengthening techniques: they are lightweight, relatively easy to install, and are noncorrosive. Due to the characteristics of FRP materials, the behavior of FRP strengthened members, and various issues regarding the use of externally bonded reinforcement, specific guidance on the use of these systems is needed. This document offers general information on the history and use of FRP strengthening systems; a description of the unique material properties of FRP; and committee recommendations on the engineering, construction, and inspection of FRP systems used to strengthen concrete structures. The proposed guidelines are based on the knowledge gained from worldwide experimental research, analytical work, and field applications of FRP systems used to strengthen concrete structures.

Keywords: aramid fibers; bridges; buildings; carbon fibers; concrete; corrosion; crack widths; cracking; cyclic loading; deflections; development length; earthquake-resistant; fatigue; fiber-reinforced polymers; flexure; glass fiber; shear; stresses; structural analysis; structural design; time-dependent; torsion.

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PART 1—GENERAL

ACI 440.2R-02 became effective July 11, 2002.

PART 2—MATERIALS

PART 3—RECOMMENDED CONSTRUCTION REQUIREMENTS

PART 4—DESIGN RECOMMENDATIONS

PART 5—DESIGN EXAMPLES

APPENDIXES

PART 1—GENERAL

CHAPTER 1—INTRODUCTION

The strengthening or retrofitting of existing concrete structures to resist higher design loads, correct deterioration-related damage, or increase ductility has traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, steel or concrete jackets, and external post-tensioning are just some of the many traditional techniques available.

Composite materials made of fibers in a polymeric resin, also known as fiber-reinforced polymers (FRP), have emerged as an alternative to traditional materials and techniques. For the purposes of this document, an FRP system is defined as all the fibers and resins used to create the composite laminate, all applicable resins used to bond it to the concrete substrate, and all applied coatings used to protect the constituent materials. Coatings used exclusively for aesthetic reasons are not considered part of an FRP system.

FRP materials are lightweight, noncorrosive, and exhibit high tensile strength. Additionally, these materials are readily available in several forms ranging from factory-made laminates to dry fiber sheets that can be wrapped to conform to the

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FRP materials are lightweight, noncorrosive, and exhibit high tensile strength. Additionally, these materials are readily available in several forms ranging from factory-made laminates to dry fiber sheets that can be wrapped to conform to the geometry of a structure before adding the polymer resin. The relatively thin profile of cured FRP systems are often desirable in applications where aesthetics or access is a concern.

The growing interest in FRP systems for strengthening and retrofitting can be attributed to many factors. Although the fibers and resins used in FRP systems are relatively expensive compared to traditional strengthening materials like concrete and steel, labor and equipment costs to install FRP systems are often lower. FRP systems can also be used in areas with limited access where traditional techniques would be difficult to implement: for example, a slab shielded by pipe and conduit.

The basis for this document is the knowledge gained from worldwide experimental research, analytical work, and field applications of FRP strengthening systems. The recommendations in this document are intended to be conservative. Areas where further research is needed are highlighted in this document and compiled in Appendix C.

1.1—Scope and limitations

This document provides guidance for the selection, design, and installation of FRP systems for externally strengthening concrete structures. Information on material properties, design, installation, quality control, and maintenance of FRP systems used as external reinforcement is presented. This information can be used to select an FRP system for increasing the strength and stiffness of reinforced concrete beams or the ductility of columns, and other applications.

A significant body of research serves as the basis for this document. This research, conducted over the past 20 years, includes analytical studies, experimental work, and monitored field applications of FRP strengthening systems. Based on the available research, the design procedures outlined in this document are considered to be conservative. It is important to note, however, that the design procedures have not, in many cases, been thoroughly developed and proven. It is envisioned that over time these procedures will be adapted to be more accurate. For the time being, it is important to specifically point out the areas of the document that do still require research.

The durability and long-term performance of FRP materials have been the subject of much research; however, this research remains ongoing. Long-term field data are not currently available, and it is still difficult to accurately predict the life of FRP strengthening systems. The design guidelines in this document do account for environmental degradation and long-term durability by suggesting reduction factors for various environments. Long-term fatigue and creep are also addressed by stress limitations indicated in this document. These factors and limitations are considered to be conservative. As more research becomes available, however, these factors will be modified and the specific environmental conditions and loading conditions to which they should apply will be better defined. Additionally, the coupling effect of environmental conditions and loading conditions still requires further study. Caution is advised in applications where the FRP system is subjected simultaneously to extreme environmental and stress conditions.

The factors associated with the long-term durability of the FRP system do not affect the tensile modulus of the material used for design. Generally, this is reasonable given that the tensile modulus of FRP materials is not affected by environmental conditions. There may be, however, specific fibers, resins, or fiber/resin combinations for which this is not true. This document currently does not have special provisions for such materials.

Many issues regarding bond of the FRP system to the substrate remain the focus of a great deal of research. For both flexural and shear strengthening, there are many different varieties of debonding failure that can govern the strength of an FRP-strengthened member. While most of the debonding modes have been identified by researchers, more accurate methods of predicting debonding are still needed. Throughout the design procedures, significant limitations on the strain level achieved in the FRP material (and thus the stress level achieved) are imposed to conservatively account for debonding failure modes. It is envisioned that future development of these design procedures will include more thorough methods of predicting debonding.

The document does give guidance on proper detailing and installation of FRP systems to prevent many types of debonding failure modes. Steps related to the surface preparation and proper termination of the FRP system are vital in achieving the levels of strength predicted by the procedures in this document. Some research has been conducted on various methods of anchoring FRP strengthening systems (by mechanical or other means). It is important to recognize, however, that methods of anchoring these systems are highly problematic due to the brittle, anisotropic nature of composite materials. Any proposed method of anchorage should be heavily scrutinized before field implementation.

The design equations given in this document are the result of research primarily conducted on moderately sized and proportioned members. While FRP systems likely are effective on other members, such as deep beams, this has not been validated through testing. Caution should be given to applications involving strengthening of very large members or strengthening in disturbed regions (D-regions) of structural members. Where warranted, specific limitations on the size of members to be strengthened are given in this document.

This document applies only to FRP strengthening systems used as additional tensile reinforcement. It is currently not recommended to use these systems as compressive reinforcement. While FRP materials can support compressive stresses, there are numerous issues surrounding the use of FRP for compression. Microbuckling of fibers can occur if any resin voids are present in the laminate, laminates themselves can buckle if not properly adhered or anchored to the substrate, and highly unreliable compressive strengths result from misaligning fibers in the field. This document does not address the construction, quality control, and maintenance issues that would be involved with the use of the material for this purpose, nor does it address the design concerns surrounding such applications. The use of the types of FRP strengthening systems described in this document to resist compressive forces is strongly discouraged.

This document does not specifically address masonry (concrete masonry units, brick, or clay tile) construction, including masonry walls. Research completed to date, however, has shown that FRP systems can be used to strengthen masonry walls, and many of the guidelines contained in this document may be applicable (Triantafillou 1998b; Ehsani et al. 1997; and Marshall et al. 1999).

1.2—Applications and use

FRP systems can be used to rehabilitate or restore the strength of a deteriorated structural member, to retrofit or strengthen a sound structural member to resist increased loads due to changes in use of the structure, or to address design or construction errors. The engineer should determine if an FRP system is a suitable strengthening technique before selecting the type of FRP system.

To assess the suitability of an FRP system for a particular application, the engineer should perform a condition assessment of the existing structure including establishing its existing load-carrying capacity, identifying deficiencies and their causes, and determining the condition of the concrete substrate. The overall evaluation should include a thorough field inspection, a review of existing design or as-built documents, and a structural analysis in accordance with ACI 364.1R. Existing construction documents for the structure should be reviewed, including the design drawings, project specifications, as-built information, field test reports, past repair documentation, and maintenance history documentation. The engineer should conduct a thorough field investigation of the existing structure in accordance with ACI 437R or other applicable documents. The tensile strength of the concrete on surfaces where the FRP system may be installed should be evaluated by conducting a pull-off adhesion test in accordance with ACI 503R. In addition, field investigation should verify the following:

- Existing dimensions of the structural members;
- Location, size, and cause of cracks and spalls;
- Location and extent of corrosion of reinforcing steel;
- Quantity and location of existing reinforcing steel;
- In-place compressive strength of concrete; and
- Soundness of the concrete, especially the concrete cover, in all areas where the FRP system is to be bonded to the concrete.

The load-carrying capacity of the existing structure should be based on the information gathered in the field investigation, the review of design calculations and drawings, and as determined by analytical or other suitable methods. Load tests or other methods can be incorporated into the overall evaluation process if deemed appropriate.

The engineer should survey the available literature and consult with FRP system manufacturers to ensure the selected FRP system and protective coating are appropriate for the intended application.

1.2.1 *Strengthening limits*—Some engineers and system manufacturers have recommended that the increase in the load-carrying capacity of a member strengthened with an FRP system be limited. The philosophy is that a loss of FRP reinforcement should not cause member failure. Specific guidance, including load combinations for assessing member integrity after loss of the FRP system, is provided in Part 4.

FRP systems used to increase the strength of an existing member should be designed in accordance with Part 4, which includes a comprehensive discussion of load limitations, sound load paths, effects of temperature and environment on FRP systems, loading considerations, and effects of reinforcing steel corrosion on FRP system integrity.

1.2.2 *Fire and life safety*—FRP-strengthened structures should comply with all applicable building and fire codes. Smoke and flame spread ratings should be determined in accordance with ASTM E 84. Coatings can be used to limit smoke and flame spread.

Due to the low temperature resistance of most fiber-reinforced polymer materials, the strength of externally bonded FRP systems is assumed to be lost completely in a fire. For this reason, the structural member without the FRP system should possess sufficient strength to resist all applicable loads during a fire. Specific guidance, including load combinations and a rational approach to calculating structural fire endurance, is given in Part 4.

The fire endurance of FRP-strengthened concrete members may be improved through the use of certain resins, coatings, or other methods of fire protection, but these have not been sufficiently demonstrated to insulate the FRP system from the temperatures reached during a fire.

1.2.3 *Maximum service temperature*—The physical and mechanical properties of the resin components of FRP systems are influenced by temperature and degrade above their glass-transition temperature T_g. The T_g is the midpoint of the temperature range over which the resin changes from a hard brittle state to a softer plastic state. This change in state will degrade the properties of the cured laminates. The T_g is unique to each FRP system and ranges from 140 to 180 F (60 to 82 C) for existing, commercially available FRP systems. The maximum service temperature of an FRP system should not exceed the T_g of the FRP system. The T_g for a particular FRP system can be obtained from the system manufacturer.

1.2.4 *Minimum concrete substrate strength*—FRP systems work on sound concrete and should not be considered for applications on structural members containing corroded reinforcing steel or deteriorated concrete unless the substrate is repaired in accordance with Section 5.4. Concrete distress, deterioration, and corrosion of existing reinforcing steel should be evaluated and addressed before the application of the FRP system. Concrete deterioration concerns include, but are not limited to, alkali-silica reactions, delayed ettringite formation, carbonation, longitudinal cracking around corroded reinforcing steel, and laminar cracking at the location of the steel reinforcement.

The condition and strength of the substrate should be evaluated to determine its capacity for strengthening of the member with externally bonded FRP reinforcement. The bond between repair materials and original concrete should satisfy the recommendations of ACI 503R or Section 3.1 of ICRI Guideline No. 03733.

The existing concrete substrate strength is an important parameter for bond-critical applications, including flexure or shear strengthening. It should possess the necessary strength to develop the design stresses of the FRP system through bond. The substrate, including all bond surfaces between repaired areas and the original concrete, should have sufficient direct tensile and shear strength to transfer force to the FRP system. The tensile strength should be at least 200 psi (1.4 MPa) as determined by using a pull-off type adhesion test as in ACI 503R or ASTM D 4541. FRP systems should not be used when the concrete substrate has a compressive strength (f_c') less than 2500 psi (17 MPa). Contact-critical applications, such as column wrapping for confinement that rely only on intimate contact between the FRP system and the concrete, are not governed by this minimum value. Design stresses in the FRP system are developed by deformation or dilation of the concrete section in contact-critical applications.

The application of FRP systems will not stop the ongoing corrosion of existing reinforcing steel. If steel corrosion is evident or is degrading the concrete substrate, placement of FRP reinforcement is not recommended without arresting the ongoing corrosion and repairing any degradation to the substrate.

1.3—Use of proprietary FRP systems

This document refers specifically to commercially available, proprietary FRP systems consisting of fibers and resins combined in a specific manner and installed by a specific method. These systems have been developed through material characterization and structural testing. Untested combinations of fibers and resins could result in an unexpected range of properties as well as potential material incompatibilities. Any FRP system considered for use should have sufficient test data demonstrating adequate performance of the entire system in similar applications, including its method of installation.

The use of FRP systems developed through material characterization and structural testing, including well-documented proprietary systems, is recommended. The use of untested combinations of fibers and resins should be avoided. A comprehensive set of test standards for FRP systems is being developed by several organizations, including ASTM, ACI, ICRI, and the Intelligent Sensing for Innovative Structures organization (ISIS). Available standards from these organizations are outlined in Appendix B.

1.4—Definitions and acronyms

The following definitions clarify terms pertaining to FRP that are not commonly used in the reinforced concrete practice. These definitions are specific to this document and are not applicable to other ACI documents.

AFRP—Aramid fiber-reinforced polymer.

Batch—Quantity of material mixed at one time or in one continuous process.

Binder—Chemical treatment applied to the random arrangement of fibers to give integrity to mats, roving, and fabric. Specific binders are utilized to promote chemical compatibility with the various laminating resins used.

Bond-critical applications—Applications of FRP systems for strengthening structural members that rely on bond to the concrete substrate; flexural and shear strengthening of beams and slabs are examples of bond-critical applications.

Catalyst—A substance that accelerates a chemical reaction and enables it to proceed under conditions more mild than otherwise required and that is not, itself, permanently changed by the reaction. See **Initiator** or **Hardener**.

CFR—Code of Federal Regulations.

CFRP—Carbon fiber-reinforced polymer (includes graphite fiber-reinforced polymer).

Composite—A combination of two or more constituent materials differing in form or composition on a macroscale. Note: The constituents retain their identities; that is, they do not dissolve or merge completely into one another, although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another.

Concrete substrate—The existing concrete or any cementitious repair materials used to repair or replace the existing concrete. The substrate can consist entirely of existing concrete, entirely of repair materials, or of a combination of existing concrete and repair materials. The substrate includes the surface to which the FRP system is installed.

Contact-critical applications—Applications of FRP systems that rely on continuous intimate contact between the concrete substrate and the FRP system. In general, contact-critical applications consist of FRP systems that completely wrap around the perimeter of the section. For most contact-critical applications the FRP system is bonded to the concrete to facilitate installation but does not rely on that bond to perform as intended. Confinement of columns for seismic retrofit is an example of a contact-critical application.

Creep-rupture—The gradual, time-dependent reduction of tensile strength due to continuous loading that leads to failure of the section.

Cross-link—A chemical bond between polymer molecules. Note: an increased number of cross-links per polymer molecule increases strength and modulus at the expense of ductility.

Cure of FRP systems—The process of causing the irreversible change in the properties of a thermosetting resin by chemical reaction. Cure is typically accomplished by addition of curing (cross-linking) agents or initiators, with or without heat and pressure. Full cure is the point at which a resin reaches the specified properties. Undercure is a condition where specified properties have not been reached.

Curing agent—A catalytic or reactive agent that causes polymerization when added to a resin. Also called hardener or initiator.

Debonding—A separation at the interface between the substrate and the adherent material.

Degradation—A decline in the quality of the mechanical properties of a material.

Delamination—A separation along a plane parallel to the surface, as in the separation of the layers of the FRP laminate from each other.

Development length, FRP—The bonded distance required for transfer of stresses from the concrete to the FRP so as to develop the strength of the FRP system. The development length is a function of the strength of the substrate and the rigidity of the bonded FRP.

Durability, FRP—The ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

E-glass—A family of glass with a calcium alumina borosilicate composition and a maximum alkali content of 2.0%. A general-purpose fiber that is used in reinforced polymers.

Epoxy—A thermosetting polymer that is the reaction product of epoxy resin and an amino hardener. (See also **Epoxy resin**.)

Epoxy resin—A class of organic chemical-bonding systems used in the preparation of special coatings or adhesives for concrete as binders in epoxy-resin mortars and concretes.

Fabric—Arrangement of fibers held together in two dimensions. A fabric can be woven, nonwoven, knitted, or stitched. Multiple layers of fabric may be stitched together. Fabric architecture is the specific description of fibers, directions, and construction of the fabric.

Fiber—Any fine thread-like natural or synthetic object of mineral or organic origin. Note: This term is generally used for materials whose length is at least 100 times its diameter.

Fiber, aramid—Highly oriented organic fiber derived from polyamide incorporating into an aromatic ring structure.

Fiber, carbon—Fiber produced by heating organic precursor materials containing a substantial amount of carbon, such as rayon, polyacrylonitrile (PAN), or pitch in an inert environment.

Fiber, glass—Fiber drawn from an inorganic product of fusion that has cooled without crystallizing. Types of glass fibers include alkali resistant (AR-glass), general purpose (E-glass), and high strength (S-glass).

Fiber content—The amount of fiber present in a composite. Note: This usually is expressed as a percentage volume fraction or weight fraction of the composite.

Fiber fly—Short filaments that break off dry fiber tows or yarns during handling and become airborne; usually classified as a nuisance dust.

Fiberglass—A composite material consisting of glass fibers in resin.

Fiber-reinforced polymer (FRP)—A general term for a composite material that consists of a polymer matrix reinforced with cloth, mat, strands, or any other fiber form. See **Composite**.

Fiber volume fraction—The ratio of the volume of fibers to the volume of the composite.

Fiber weight fraction—The ratio of the weight of fibers to the weight of the composite.

Filament—See **Fiber**.

Filler—A relatively inert substance added to a resin to alter its properties or to lower cost or density. Sometimes the term is used specifically to mean particulate additives. Also called extenders.

Fire retardant—Chemicals that are used to reduce the tendency of a resin to burn; these can be added to the resin or coated on the surface of the FRP.

Flow—The movement of uncured resin under pressure or gravity loads.

FRP—Fiber reinforced polymer; formerly, fiber-reinforced plastic.

GFRP—Glass fiber-reinforced polymer.

Glass fiber—An individual filament made by drawing or spinning molten glass through a fine orifice. A continuous filament is a single glass fiber of great or indefinite length. A staple fiber is a glass fiber of relatively short length, generally less than 17 in. (0.43 m), the length related to the forming or spinning process used.

Glass transition temperature (T_g)—The midpoint of the temperature range over which an amphoras material (such as glass or a high polymer) changes from (or to) a brittle, vitreous state to (or from) a plastic state.

Grid, FRP—A two-dimensional (planar) or three-dimensional (spatial) rigid array of interconnected FRP bars that form a contiguous lattice that can be used to reinforce concrete. The lattice can be manufactured with integrally connected bars or made of mechanically connected individual bars.

Hardener—1) a chemical (including certain fluosilicates or sodium silicate) applied to concrete floors to reduce wear and dusting; or 2) in a two-component adhesive or coating, the chemical component that causes the resin component to cure.

Impregnate—In fiber-reinforced polymers, to saturate the fibers with resin.

Initiator—A source of free radicals, which are groups of atoms that have at least one unpaired electron, used to start the curing process for unsaturated polyester and vinyl ester resins. Peroxides are the most common source of free radicals. See **Catalyst**.

Interface—The boundary or surface between two different, physically distinguishable media. On fibers, the contact area between fibers and coating/sizing.

Interlaminar shear—Shearing force tending to produce a relative displacement between two laminae in a laminate along the plane of their interface.

Laminate—One or more layers of fiber bound together in a cured resin matrix.

Layup—The process of placing the FRP reinforcing material in position for molding.

Mat—A fibrous material for reinforced polymer, consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or long random filaments loosely held together with a binder.

Matrix—In the case of fiber-reinforced polymers, the materials that serve to bind the fibers together, transfer load to the fibers, and protect them against environmental attack and damage due to handling.

Monomer—An organic molecule of relatively low molecular weight that creates a solid polymer by reacting with itself or other compounds of low molecular weight or both.

MSDS—Material safety data sheet.

OSHA—Occupational Safety and Health Administration.

PAN—Polyacrylonitrile, a precursor fiber used to make carbon fiber.

Phenolic—A thermosetting resin produced by the condensation of an aromatic alcohol with an aldehyde, particularly of phenol with formaldehyde.

Pitch—Petroleum or coal tar precursor base used to make carbon fiber.

Ply—A single layer of fabric or mat; multiple plies, when molded together, make up the laminate.

Polyester—One of a large group of synthetic resins, mainly produced by the reaction of dibasic acids with dihydroxy alcohols; commonly prepared for application by mixing with a vinyl-group monomer and free-radical catalysts at ambient temperatures and used as binders for resin mortars and concretes, fiber laminates (mainly glass), adhesives, and the like. Commonly referred to as “unsaturated polyester.”

Polymer—A high molecular weight organic compound, natural or synthetic, containing repeating units.

Polymerization—The reaction in which two or more molecules of the same substance combine to form a compound containing the same elements and in the same proportions but of higher molecular weight.

Polyurethane—Reaction product of an isocyanate with any of a wide variety of other compounds containing an active hydrogen group; used to formulate tough, abrasion-resistant coatings.

Postcuring, FRP—Additional elevated-temperature curing that increases the level of polymer cross-linking; final properties of the laminate or polymer are enhanced.

Pot life—Time interval after preparation during which a liquid or plastic mixture is to be used.

Prepreg—A fiber or fiber sheet material containing resin that is advanced to a tacky consistency. Multiple plies of prepreg are typically cured with applied heat and pressure; also preimpregnated fiber or sheet.

Pultrusion—A continuous process for manufacturing composites that have a uniform cross-sectional shape. The process consists of pulling a fiber-reinforcing material through a resin impregnation bath then through a shaping die where the resin is subsequently cured.

Resin—Polymeric material that is rigid or semirigid at room temperature, usually with a melting point or glass transition temperature above room temperature.

Resin content—The amount of resin in a laminate, expressed as either a percentage of total mass or total volume.

Roving—A number of yarns, strands, tows, or ends of fibers collected into a parallel bundle with little or no twist.

Sheet, FRP—A dry, flexible ply used in wet layup FRP systems. Unidirectional FRP sheets consist of continuous fibers aligned in one direction and held together in-plane to create a ply of finite width and length. Fabrics are also referred to as sheets. See **Fabric**, **Ply**.

Shelf life—The length of time packaged materials can be stored under specified conditions and remain usable.

Sizing—Surface treatment or coating applied to filaments to improve the filament-to-resin bond and to impart processing and durability attributes.

Sustained stress—Stress caused by unfactored sustained loads including dead loads and the sustained portion of the live load.

Thermoset—Resin that is formed by cross-linking polymer chains. Note: A thermoset cannot be melted and recycled because the polymer chains form a three-dimensional network.

Tow—An untwisted bundle of continuous filaments.

Vinyl ester—A thermosetting resin containing both vinyl and ester components, and cured by additional polymerization initiated by free-radical generation. Vinyl esters are used as binders for fiber laminates and adhesives.

VOC—Volatile organic compounds; any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, or carbonates, and ammonium carbonate, that participates in atmospheric photochemical reactions, such as ozone depletion.

Volume fraction—The proportion from 0.0 to 1.0 of a component within the composite, measured on a volume basis, such as fiber-volume fraction.

Wet layup—A method of making a laminate product by applying the resin system as a liquid when the fabric or mat is put in place.

Wet-out—The process of coating or impregnating roving, yarn, or fabric in which all voids between the strands and filaments are filled with resin; it is also the condition at which this state is achieved.

Witness panel—A small field sample FRP panel, manufactured on-site in a noncritical area at conditions similar to the actual construction. The panel can be later tested to determine mechanical and physical properties to confirm expected properties of the installed FRP laminate.

Yarn—An assemblage of twisted filaments, fibers, or strands, formed into a continuous length that is suitable for use in weaving textile materials.

1.5—Notation

A_f = nt_fw_f, area of FRP external reinforcement, in.^{2} (mm^2)

A_{fv} = area of FRP shear reinforcement with spacing s, in.^{2} (mm^2)

A_g = gross area of section, in.^{2} (mm^2)

A_s = area of nonprestressed steel reinforcement, in.^{2} (mm^2)

A_{st} = total area of longitudinal reinforcement, in.^{2} (mm^2)

b = width of rectangular cross section, in. (mm)

b_w = web width or diameter of circular section, in. (mm)

c = distance from extreme compression fiber to the neutral axis, in. (mm)

C_E = environmental-reduction factor

d = distance from extreme compression fiber to the neutral axis, in. (mm)

d_f = depth of FRP shear reinforcement as shown in Fig. 10.2, in. (mm)

E_c = modulus of elasticity of concrete, psi (MPa)

E_f = tensile modulus of elasticity of FRP, psi (MPa)

E_s = modulus of elasticity of steel, psi (MPa)

f_c = compressive stress in concrete, psi (MPa)

f'_c = specified compressive strength of concrete, psi (MPa)

$\sqrt{f'_c}$ = square root of specified compressive strength of concrete

f'_{cc} = apparent compressive strength of confined concrete, psi (MPa)

f_f = stress level in the FRP reinforcement, psi (MPa)

$f_{f,s}$ = stress level in the FRP caused by a moment within the elastic range of the member, psi (MPa)

f_{fe} = effective stress in the FRP; stress level attained at section failure, psi (MPa)

f^*_{fu} = ultimate tensile strength of the FRP material as reported by the manufacturer, psi (MPa)

f_{fu} = design ultimate tensile strength of FRP, psi (MPa)

$\overline{f_{fu}}$ = mean ultimate strength of FRP based on a population of 20 or more tensile tests per ASTM D 3039, psi (MPa)

f_l = confining pressure due to FRP jacket, psi (MPa)

f_s = stress in nonprestressed steel reinforcement, psi (MPa)

$f_{s,s}$ = stress level in nonprestressed steel reinforcement at service loads, psi (MPa)

f_y = specified yield strength of nonprestressed steel reinforcement, psi (MPa)

h = overall thickness of a member, in. (mm)

I_{cr} = moment of inertia of cracked section transformed to concrete, in.^{4} (mm^4)

k = ratio of the depth of the neutral axis to the reinforcement depth measured on the same side of neutral axis

k_f = stiffness per unit width per ply of the FRP reinforcement, lb/in. (N/mm); $k_f = E_f t_f$

k_1 = modification factor applied to κ_v to account for the concrete strength

k_2 = modification factor applied to κ_v to account for the wrapping scheme

L_e = active bond length of FRP laminate, in. (mm)

l_{df} = development length of FRP system, in. (mm)

M_{cr} = cracking moment, in.-lb (N-mm)

M_n = nominal moment strength, in.-lb (N-mm)

M_s = moment within the elastic range of the member, in.-lb (N-mm)

M_u = factored moment at section, in.-lb (N-mm)

n = number of plies of FRP reinforcement

p^*_{fu} = ultimate tensile strength per unit width per play of the FRP reinforcement, lb/in. (N/mm); $p^*_{fu} = f^*_{fu}t_f$

$\overline{p_{fu}}$ = mean tensile strength per unit width per ply of the reinforcement, lb/in. (N/mm)

P_n = nominal axial load strength at given eccentricity, lb (N)

r = radius of the edges of a square or rectangular section confined with FRP, in. (mm)

R_n = nominal strength of a member

$R_{n\phi}$ = nominal strength of a member subjected to the elevated temperatures associated with a fire

S_{DL} = dead load effects

s_f = spacing FRP shear reinforcing as described in Fig. 10.2, in. (mm)

S_{LL} = live load effects

t_f = nominal thickness of one ply of the FRP reinforcement, in. (mm)

T_g = glass-transition temperature, °F (°C)

V_c = nominal shear strength provided by concrete with steel flexural reinforcement, lb (N)

V_n = nominal shear strength, lb (N)

V_s = nominal shear strength provided by steel stirrups, lb (N)

V_f = nominal shear strength provided by FRP stirrups, lb

w_f = width of the FRP reinforcing plies, in. (mm)

α = angle of inclination of stirrups or spirals, degrees

α_L = longitudinal coefficient of thermal expansion, in./in./°F (mm/mm/°C)

α_T = transverse coefficient of thermal expansion, in./in./°F (mm/mm/°C)

β_1 = ratio of the depth of the equivalent rectangular stress block to the depth of the neutral axis

ε_b = strain level in the concrete substrate developed by a given bending moment (tension in positive), in./in. (mm/mm)

ε_{bi} = strain level in the concrete substrate at the time of the FRP installation (tension is positive), in./in. (mm/mm)

ε_c = stain level in the concrete, in./in. (mm/mm)

ε_{cc}' = maximum usable compressive strain of FRP confined concrete, in./in. (mm/mm)

ε_{cu} = maximum usable compressive strain of concrete, in./in., (mm/mm)

ε_f = strain level in the FRP reinforcement, in./in. (mm/mm)

ε_{fe} = effective strain level in FRP reinforcement; strain level attained at section failure, in./in. (mm/mm)

ε_{fu} = design rupture strain of FRP reinforcement, in./in. (mm/mm)

$\overline{\varepsilon_{fu}}$ = mean rupture stain of FRP reinforcement based on a population of 20 or more tensile tests per ASTM D 3039, in./in. (mm/mm)

ε_{fu}^* = ultimate rupture strain of the FRP reinforcement, in./in. (mm/mm)

ε_s = strain level in the nonprestessed steel reinforcement, in./in./ (mm)

ε_{sy} = strain corresponding to the yield strength of nonprestressed steel reinforcement

ϕ = strength reduction factor

γ = multiplier on f_c' to determine the intensity of an equivalent rectangular stress distribution for concrete

κ_a = efficiency factor for FRP reinforcement (based on the section geometry)

κ_m = bond-dependent coefficient for flexure

κ_v = bond-dependent coefficient for shear

ρ_f = FRP reinforcement ratio

ρ_g = ratio of the area of longitudinal steel reinforcement to the cross-sectional area of a compression member

ρ_s = ratio of nonprestressed reinforcement

σ = standard deviation

ψ_f = additional FRP strength-reduction factor

CHAPTER 2—BACKGROUND INFORMATION

Externally bonded FRP systems have been used to strengthen and retrofit existing concrete structures around the world since the mid 1980s. The number of projects utilizing FRP systems worldwide has increased dramatically, from a few 10 years ago to several thousand today (Bakis et al. 2002). Structural elements strengthened with externally bonded FRP systems include beams, slabs, columns, walls, joints/connections, chimneys and smokestacks, vaults, domes, tunnels, silos, pipes, and trusses. Externally bonded FRP systems have also been used to strengthen masonry, timber, steel, and cast-iron structures. The idea of strengthening concrete structures with externally bonded reinforcement is not new. Externally bonded FRP systems were developed as alternates to traditional external reinforcing techniques like steel plate bonding and steel or concrete column jacketing. The initial development of externally bonded FRP systems for the retrofit of concrete structures occurred in the 1980s in both Europe and Japan.

2.1—Historical development

In Europe, FRP systems were developed as alternates to steel plate bonding. Bonding steel plates to the tension zones of concrete members with epoxy resins were shown to be viable techniques for increasing their flexural strengths (Fleming and King 1967). This technique has been used to strengthen many bridges and buildings around the world. Because steel plates can corrode, leading to a deterioration of the bond between the steel and concrete, and that are difficult to install, requiring the use of heavy equipment, researchers have looked to FRP materials as an alternative to steel. Experimental work using FRP materials for retrofitting concrete structures was reported as early as 1978 in Germany (Wolf and Miessler 1989). Research in Switzerland led to the first applications of externally bonded FRP systems to reinforced concrete bridges for flexural strengthening (Meier 1987; Rostasy 1987).

FRP systems were first applied to reinforced concrete columns for providing additional confinement in Japan in the 1980s (Fardis and Khalili 1981; Katsumata et al. 1987). A sudden increase in the use of FRPs in Japan was observed after the 1995 Hyogoken Nanbu earthquake (Nanni 1995).

The United States has had a long and continuous interest in fiber-based reinforcement for concrete structures since the 1930s. Actual development and research into the use of these materials for retrofitting concrete structures, however, started in the 1980s through the initiatives of the National Science Foundation (NSF) and the Federal Highway Administration (FHWA). The research activities led to the construction of many field projects encompassing a wide variety of environmental conditions. Previous research and field applications for FRP rehabilitation and strengthening are described in ACI 440R-96 and conference proceedings (Japan Concrete

Institute 1997; Neale 2000; Dolan et al. 1999; Sheheta et al. 1999; Saadatmanesh and Ehsani 1998; Benmokrane and Rahman 1998; Neale and Labossière 1997; Hassan and Rizkalla 2002).

The development of codes and standards for externally bonded FRP systems is ongoing in Europe, Japan, Canada, and the United States. Within the last 10 years, the Japan Society of Civil Engineers (JSCE) and the Japan Concrete Institute (JCI) and the Railway Technical Research Institute (RTRI) published several documents related to the use of FRP materials in concrete structures.

In Europe, Task Group 9.3 of the International Federation for Structural Concrete (FIB) recently published a bulletin on design guidelines for externally bonded FRP reinforcement for reinforced concrete structures (FIB 2001).

The Canada Standards Association and ISIS have been active in developing guidelines for FRP systems. Section 16, "Fiber Reinforced Concrete," of the Canadian Highway Bridge Design Code was completed in 2000 (CSA S806-02) and the Canadian Standards Association (CSA) recently approved the code "Design and Construction of Building Components with Fiber Reinforced Polymers" (CSA S806-02).

In the United States, criteria for evaluating FRP systems are becoming available to the construction industry (AC125 1997; CALTRANS 1996; Hawkins et al. 1998).

2.2—Commercially available externally bonded FRP systems

FRP systems come in a variety of forms, including wet layup systems and precured systems. FRP system forms can be categorized based on how they are delivered to the site and installed. The FRP system and its form should be selected based on the acceptable transfer of structural loads and the ease and simplicity of application. Common FRP system forms suitable for the strengthening of structural members are listed as follows:

2.2.1 *Wet layup systems*—Wet layup FRP systems consist of dry unidirectional or multidirectional fiber sheets or fabrics impregnated with a saturating resin on-site. The saturating resin, along with the compatible primer and putty, is used to bond the FRP sheets to the concrete surface. Wet layup systems are saturated in-place and cured in-place and, in this sense, are analogous to cast-in-place concrete. Three common types of wet layup systems are listed as follows:

1. Dry unidirectional fiber sheets where the fibers run predominantly in one planar direction;
2. Dry multidirectional fiber sheets or fabrics where the fibers are oriented in at least two planar directions; and
3. Dry fiber tows that are wound or otherwise mechanically applied to the concrete surface. The dry fiber tows are impregnated with resin on-site during the winding operation.

2.2.2 *Prepreg systems*—Prepreg FRP systems consist of uncured unidirectional or multidirectional fiber sheets or fabrics that are preimpregnated with a saturating resin in the manufacturer's facility. Prepreg systems are bonded to the concrete surface with or without an additional resin application, depending upon specific system requirements. Prepreg systems are saturated off-site and, like wet layup systems, cured in place. Prepreg systems usually require additional heating for curing. Prepreg system manufacturers should be consulted for storage and shelf-life recommendations and curing procedures. Three common types of prepreg FRP systems are listed as follows:

1. Preimpregnated unidirectional fiber sheets where the fibers run predominantly in one planar direction;
2. Preimpregnated multidirectional fiber sheets or fabrics where the fibers are oriented in at least two planar directions; and
3. Preimpregnated fiber tows that are wound or otherwise mechanically applied to the concrete surface.

2.2.3 *Precured systems*—Precured FRP systems consist of a wide variety of composite shapes manufactured off-site. Typically, an adhesive along with the primer and putty is used to bond the precured shapes to the concrete surface. The system manufacturer should be consulted for recommended installation procedures. Precured systems are analogous to precast concrete. Three common types of precured systems are listed as follows:

1. Precured unidirectional laminate sheets, typically delivered to the site in the form of large flat stock or as thin ribbon strips coiled on a roll;
2. Precured multidirectional grids, typically delivered to the site coiled on a roll;
3. Precured shells, typically delivered to the site in the form of shell segments cut longitudinally so they can be opened and fitted around columns or other members; multiple shell layers are bonded to the concrete and to each other to provide seismic confinement.

2.2.4 *Other FRP forms*—Other FRP forms are not covered in this document. These include cured FRP rigid rod and flexible strand or cable (Saadatmanesh and Tannous 1999a; Dolan 1999; Fukuyama 1999; ACI 440R-96 and ACI 440.1R-01).

PART 2—MATERIALS

CHAPTER 3—CONSTITUENT MATERIALS AND PROPERTIES

The physical and mechanical properties of FRP materials presented in this chapter explain the behavior and properties affecting their use in concrete structures. The effects of factors such as loading history and duration, temperature, and moisture on the properties of FRP are discussed.

FRP-strengthening systems come in a variety of forms (wet layup, prepreg, precured). Factors such as fiber volume, type of fiber, type of resin, fiber orientation, dimensional effects, and quality control during manufacturing all play a role in establishing the characteristics of an FRP material. The material characteristics described in this chapter are generic and do not apply to all commercially available products. Standard test methods are being developed by several organizations including ASTM, ACI, and ISIS to characterize certain FRP products. In the interim, however, the engineer is encouraged to consult with the FRP system manufacturer to obtain the relevant characteristics for a specific product and the applicability of those characteristics.

3.1—Constituent materials

The constituent materials used in commercially available FRP repair systems, including all resins, primers, putties, saturants, adhesives, and fibers, have been developed for the strengthening of structural concrete members based on materials and structural testing.

3.1.1 *Resins*—A wide range of polymeric resins, including primers, putty fillers, saturants, and adhesives, are used with FRP systems. Commonly used resin types including epoxies, vinyl esters, and polyesters have been formulated for use in

Table 3.1—Typical densities of FRP materials, lb/ft^3 (g/cm^3)

Steel	GFRP	CFRP	AFRP
490 (7.9)	75 to 130 (1.2 to 2.1)	90 to 100 (1.5 to 1.6)	75 to 90 (1.2 to 1.5)

Table 3.2—Typical coefficients of thermal expansion for FRP materials*

Direction	Coefficient of thermal expansion, × 10^{-6}/°F (× 10^{-6}/°C)		
	GFRP	CFRP	AFRP
Longitudinal, α_L	3.3 to 5.6 (6 to 10)	–0.6 to 0 (–1 to 0)	–3.3 to –1.1 (–6 to –2)
Transverse, α_T	10.4 to 12.6 (19 to 23)	12 to 27 (22 to 50)	33 to 44 (60 to 80)

*Typical values for fiber-volume fractions ranging from 0.5 to 0.7.

a wide range of environmental conditions. FRP system manufacturers use resins that have the following characteristics:

- Compatibility with and adhesion to the concrete substrate;
- Compatibility with and adhesion to the FRP composite system;
- Resistance to environmental effects, including but not limited to moisture, salt water, temperature extremes, and chemicals normally associated with exposed concrete;
- Filling ability;
- Workability;
- Pot life consistent with the application;
- Compatibility with and adhesion to the reinforcing fiber; and
- Development of appropriate mechanical properties for the FRP composite.

3.1.1.1 *Primer*—The primer is used to penetrate the surface of the concrete, providing an improved adhesive bond for the saturating resin or adhesive.

3.1.1.2 *Putty fillers*—The putty is used to fill small surface voids in the substrate, such as bug holes, and to provide a smooth surface to which the FRP system can bond. Filled surface voids also prevent bubbles from forming during curing of the saturating resin.

3.1.1.3 *Saturating resin*—The saturating resin is used to impregnate the reinforcing fibers, fix them in place, and provide a shear load path to effectively transfer load between fibers. The saturating resin also serves as the adhesive for wet layup systems, providing a shear load path between the previously primed concrete substrate and the FRP system.

3.1.1.4 *Adhesives*—Adhesives are used to bond precured FRP laminate systems to the concrete substrate. The adhesive provides a shear load path between the concrete substrate and the FRP reinforcing laminate. Adhesives are also used to bond together multiple layers of precured FRP laminates.

3.1.1.5 *Protective coatings*—The protective coating is used to protect the bonded FRP reinforcement from potentially damaging environmental effects. Coatings are typically applied to the exterior surface of the cured FRP system after the adhesive or saturating resin has cured.

3.1.2 *Fibers*—Continuous glass, aramid, and carbon fibers are common reinforcements used with FRP systems. The fibers give the FRP system its strength and stiffness. Typical ranges of the tensile properties of fibers are given in Appendix A. A more detailed description of fibers is given in ACI 440R.

3.2—Physical properties

3.2.1 *Density*—FRP materials have densities ranging from 75 to 130 lb/ft^3 (1.2 to 2.1 g/cm^3), which is four to six times lower than that of steel (Table 3.1). The reduced density leads to lower transportation costs, reduces added dead load on the structure, and can ease handling of the materials on the project site.

3.2.2 *Coefficient of thermal expansion*—The coefficients of thermal expansion of unidirectional FRP materials differ in the longitudinal and transverse directions, depending on the types of fiber, resin, and volume fraction of fiber. Table 3.2 lists the longitudinal and transverse coefficients of thermal expansion for typical unidirectional FRP materials. Note that a negative coefficient of thermal expansion indicates that the material contracts with increased temperature and expands with decreased temperature. For reference, concrete has a coefficient of thermal expansion that varies from 4×10^{-6} to 6×10^{-6}/°F (7×10^{-6} to 11×10^{-6}/°C) and is usually assumed to be isotropic (Mindess and Young 1981). Steel has an isotropic coefficient of thermal expansion of 6.5×10^{-6}/°F (11.7×10^{-6}/°C). See Section 8.3.1 for design considerations regarding thermal expansion.

3.2.3 *Effects of high temperatures*—Beyond the T_g, the elastic modulus of a polymer is significantly reduced due to changes in its molecular structure. The value of T_g depends on the type of resin but is normally in the region of 140 to 180 °F (60 to 82 °C). In an FRP composite material, the fibers, which exhibit better thermal properties than the resin, can continue to support some load in the longitudinal direction until the temperature threshold of the fibers is reached. This can occur at temperatures near 1800 °F (1000 °C) for glass fibers and 350 °F (175 °C) for aramid fibers. Carbon fibers are capable of resisting temperatures in excess of 500 °F (275 °C). Due to a reduction in force transfer between fibers through bond to the resin, however, the tensile properties of the overall composite are reduced. Test results have indicated that temperatures of 480 °F (250 °C), much higher than the resin T_g, will reduce the tensile strength of GFRP and CFRP materials in excess of 20% (Kumahara et al. 1993). Other properties affected by the shear transfer through the resin, such as bending strength, are reduced significantly at lower temperatures (Wang and Evans 1995).

For bond-critical applications of FRP systems, the properties of the polymer at the fiber-concrete interface are essential in maintaining the bond between FRP and concrete. At a temperature close to its T_g, however, the mechanical properties of the polymer are significantly reduced, and the polymer begins to loose its ability to transfer stresses from the concrete to the fibers.

3.3—Mechanical properties and behavior

3.3.1 *Tensile behavior*—When loaded in direct tension, FRP materials do not exhibit any plastic behavior (yielding) before rupture. The tensile behavior of FRP materials consisting of one type of fiber material is characterized by a linearly elastic stress-strain relationship until failure, which is sudden and can be catastrophic.

The tensile strength and stiffness of an FRP material is dependent on several factors. Because the fibers in an FRP material are the main load-carrying constituent, the type of fiber, the orientation of the fibers, and the quantity of fibers primarily govern the tensile properties of the FRP material. Due to the primary role of the fibers and methods of application, the properties of an FRP repair system are sometimes reported based on the net-fiber area. In other instances, the reported properties are based on the gross-laminate area.

The gross-laminate area of an FRP system is calculated using the total cross-sectional area of the cured FRP system, including all fibers and resin. The gross-laminate area is typically used for reporting precured laminate properties where the cured thickness is constant and the relative proportion of fiber and resin is controlled.

The net-fiber area of an FRP system is calculated using the known area of fiber, neglecting the total width and thickness of the cured system; thus, resin is excluded. The net-fiber area is typically used for reporting properties of wet layup systems that use manufactured fiber sheets and field-installed resins. The wet layup installation process leads to a controlled fiber content and a variable resin content.

System properties reported using the gross-laminate area have higher relative thickness dimensions and lower relative strength and modulus values, whereas system properties reported using the net-fiber area have lower relative thickness dimensions and higher relative strength and modulus values. Regardless of the basis for the reported values, the load-carrying strength ($f_{fu}A_f$) and stiffness (A_fE_f) remain constant. (The calculation of FRP system properties using both gross-laminate and net-fiber property methods is illustrated in Part 5.) Properties reported based on the net-fiber area are not the properties of the bare fibers. The properties of an FRP system should be characterized as a composite, recognizing not just the material properties of the individual fibers but also the efficiency of the fiber-resin system, the fabric architecture, and the method used to create the composite. The mechanical properties of all FRP systems, regardless of form, should be based on the testing of laminate samples with a known fiber content.

The tensile properties of some commercially available FRP strengthening systems are given in Appendix A. The tensile properties of a particular FRP system, however, should be obtained from the FRP system manufacturer. Manufacturers should report an ultimate tensile strength defined by this guide as the mean tensile strength of a sample of test specimens minus three times the standard deviation ($f_{fu}^* = f_{fu} - 3\sigma$) and, similarly, report an ultimate rupture strain ($\varepsilon_{fu}^* = \varepsilon_{fu} - 3\sigma$). These statistically based ultimate tensile properties provide a 99.87% probability that the indicated values are exceeded (Mutsuyoshi et al. 1990). Young's modulus should be calculated as the chord modulus between 0.003 and 0.006 strain, in accordance with ASTM D 3039. A minimum number of 20 replicate test specimens should be used to determine the ultimate tensile properties. The manufacturer should provide a description of the method used to obtain the reported tensile properties, including the number of tests, mean values, and standard deviations.

3.3.2 *Compressive behavior*—Externally bonded FRP systems should not be used as compression reinforcement due to insufficient testing validating its use in this type of application. While it is not recommended to rely on externally bonded FRP systems to resist compressive stresses, the following section is presented to fully characterize the behavior of FRP materials.

Coupon tests on FRP laminates used for repair on concrete have shown that the compressive strength is lower than the tensile strength (Wu 1990). The mode of failure for FRP laminates subjected to longitudinal compression can include transverse tensile failure, fiber microbuckling, or shear failure. The mode of failure depends on the type of fiber, the fiber-volume fraction, and the type of resin. Compressive strengths of 55, 78, and 20% of the tensile strength have been reported for GFRP, CFRP, and AFRP, respectively (Wu 1990). In general, compressive strengths are higher for materials with higher tensile strengths, except in the case of AFRP where the fibers exhibit nonlinear behavior in compression at a relatively low level of stress.

The compressive modulus of elasticity is usually smaller than the tensile modulus of elasticity of FRP materials. Test reports on samples containing a 55 to 60% volume fraction of continuous E-glass fibers in a matrix of vinyl ester or isophthalic polyester resin have reported a compressive modulus of elasticity of 5000 to 7000 ksi (34,000 to 48,000 MPa) (Wu 1990). According to reports, the compressive modulus of elasticity is approximately 80% for GFRP, 85% for CFRP, and 100% for AFRP of the tensile modulus of elasticity for the same product (Ehsani 1993).

3.4—Time-dependent behavior

3.4.1 *Creep-rupture*—FRP materials subjected to a constant load over time can suddenly fail after a time period referred to as the endurance time. This type of failure is known as creep-rupture. As the ratio of the sustained tensile stress to the short-term strength of the FRP laminate increases, endurance time decreases. The endurance time also decreases under adverse environmental conditions, such as high temperature, ultraviolet-radiation exposure, high alkalinity, wet and dry cycles, or freezing-and-thawing cycles.

In general, carbon fibers are the least susceptible to creep-rupture; aramid fibers are moderately susceptible, and glass fibers are most susceptible. Creep-rupture tests have been conducted on 0.25 in. (6 mm) diameter FRP bars reinforced with glass, aramid, and carbon fibers. The FRP bars were tested at different load levels at room temperature. Results indicated that a linear relationship exists between creep-rupture strength and the logarithm of time for all load levels. The ratios of stress level at creep-rupture after 500,000 h (about 50 years) to the initial ultimate strength of the GFRP, AFRP, and CFRP bars were extrapolated to be 0.3, 0.47, and 0.91, respectively (Yamaguchi et al. 1997). Similar values have been determined elsewhere (Malvar 1998).

Recommendations on sustained stress limits imposed to avoid creep-rupture are given in the design section of this guide. As long as the sustained stress in the FRP is below the creep rupture stress limits, the strength of the FRP is available for nonsustained loads.

3.4.2 *Fatigue*—A substantial amount of data for fatigue behavior and life prediction of stand-alone FRP materials have been generated in the last 30 years (National Research Council 1991). During most of this period, aerospace materials were the primary subjects of investigation. Despite the differences in quality and consistency between aerospace and commercial-grade FRP materials, some general observations on the fatigue behavior of FRP materials can be made. Unless specifically stated otherwise, the following cases being reviewed are based on an unidirectional material with approximately 60% fiber-volume fraction and subjected to tension-tension sinusoidal cyclic loading at:

- A frequency low enough to not cause self-heating;
- Ambient laboratory environments;
- A stress ratio (ratio of minimum applied stress to maximum applied stress) of 0.1; and
- A direction parallel to the principal fiber alignment.

Test conditions that raise the temperature and moisture content of FRP materials generally degrade the ambient environment fatigue behavior.

Of all types of FRP composites for infrastructure applications, CFRP is the least prone to fatigue failure. An endurance limit of 60 to 70% of the initial static ultimate strength of CFRP is typical. On a plot of stress versus the logarithm of the number of cycles at failure (S-N curve), the downward slope of CFRP is usually about 5% of the initial static ultimate strength per decade of logarithmic life. At one million cycles, the fatigue strength is generally between 60 and 70% of the initial static ultimate strength and is relatively unaffected by the moisture and temperature exposures of concrete structures unless the resin or fiber/resin interface is substantially degraded by the environment.

In ambient-environment laboratory tests (Mandell and Meier 1983), individual glass fibers demonstrated delayed rupture caused by stress corrosion, which had been induced by the growth of surface flaws in the presence of even minute quantities of moisture. When many glass fibers are embedded into a matrix to form an FRP composite, a cyclic tensile fatigue effect of approximately 10% loss in the initial static strength per decade of logarithmic lifetime is observed (Mandell 1982). This fatigue effect is thought to be due to fiber-fiber interactions and not dependent on the stress corrosion mechanism described for individual fibers. Usually, no clear fatigue limit can be defined. Environmental factors can play an important role in the fatigue behavior of glass fibers due to their susceptibility to moisture, alkaline, and acidic solutions.

Aramid fibers, for which substantial durability data are available, appear to behave reasonably well in fatigue. Neglecting in this context the rather poor durability of all aramid fibers in compression, the tension-tension fatigue behavior of an impregnated aramid fiber strand is excellent. Strength degradation per decade of logarithmic lifetime is approximately 5 to 6% (Roylance and Roylance 1981). While no distinct endurance limit is known for AFRP, two-million-cycle endurance limits of commercial AFRP tendons for concrete applications have been reported in the range of 54 to 73% of the ultimate tensile strength (Odagiri et al. 1997). Based on these findings, Odagiri suggested that the maximum stress be set to 0.54 to 0.73 times the tensile strength. Because the slope of the applied stress versus logarithmic endurance time of AFRP is similar to the slope of the stress versus logarithmic cyclic lifetime data, the individual fibers appear to fail by a strain-limited, creep-rupture process. This lifetime-limiting mechanism in commercial AFRP bars is accelerated by exposure to moisture and elevated temperature (Roylance and Roylance 1981; Rostasy 1997).

3.5—Durability

Many FRP systems exhibit reduced mechanical properties after exposure to certain environmental factors, including temperature, humidity, and chemical exposure. The exposure environment, duration of the exposure, resin type and formulation, fiber type, and resin-curing method are some of the factors that influence the extent of the reduction in mechanical properties. These factors are discussed in more detail in Section 8.3. The tensile properties reported by the manufacturer are based on testing conducted in a laboratory environment and do not reflect the effects of environmental exposure. These properties should be adjusted in accordance with Section 8.4 to account for the anticipated service environment to which the FRP system may be exposed during its service life.

3.6—FRP system qualification

FRP systems should be qualified for use on a project on the basis of independent laboratory test data of the FRP-constituent materials and the laminates made with them, structural test data for the type of application being considered, and durability data representative of the anticipated environment. Test data provided by the FRP system manufacturer demonstrating the proposed FRP system meets all mechanical and physical design requirements including tensile strength, durability, resistance to creep, bond to substrate, and T_g should be considered but not used as the sole basis for qualification.

FRP composite systems that have not been fully tested should not be considered for use. Mechanical properties of FRP systems should be determined from tests on laminates manufactured in a process representative of their field installation. Mechanical properties should be tested in general conformance with the procedures listed in Appendix B. Modifications of standard testing procedures may be permitted to emulate field assemblies.

The specified material-qualification programs should require sufficient laboratory testing to measure the repeatability and reliability of critical properties. Testing of multiple batches of FRP materials is recommended. Independent structural testing can be used to evaluate a system's performance for the specific application.

PART 3—RECOMMENDED CONSTRUCTION REQUIREMENTS

CHAPTER 4—SHIPPING, STORAGE, AND HANDLING

4.1—Shipping

FRP system constituent materials must be packaged and shipped in a manner that conforms to all applicable federal and state packaging and shipping codes and regulations. Packaging, labeling, and shipping for thermosetting resin materials are controlled by CFR 49. Many materials are classified as corrosive, flammable, or poisonous in subchapter C (CFR 49) under "Hazardous Materials Regulations."

4.2—Storage

4.2.1 *Storage conditions*—To preserve the properties and maintain safety in the storage of FRP system constituent materials, the materials should be stored in accordance with the manufacturer's recommendations. Certain constituent materials, such as reactive curing agents, hardeners, initiators, catalysts, and cleaning solvents, have safety-related requirements and should be stored in a manner as recommended by the manufacturer and OSHA. Catalysts and initiators (usually peroxides) should be stored separately.

4.2.2 *Shelf life*—The properties of the uncured resin components can change with time, temperature, or humidity. Such conditions can affect the reactivity of the mixed system and the uncured and cured properties. The manufacturer sets a recommended shelf life within which the properties of the resin-based materials should continue to meet or exceed stated performance criteria. Any component material that has exceeded its shelf life, has deteriorated, or has been contaminated should not be used. FRP materials deemed unusable should be disposed of in a manner specified by the manufacturer and acceptable to state and federal environmental control regulations.

4.3—Handling

4.3.1 *Material safety data sheets*—Material safety data sheets (MSDS) for all FRP constituent materials and components must be obtained from the manufacturers and must be accessible at the job site.

4.3.2 *Information sources*—Detailed information on the handling and potential hazards of FRP constituent materials can be found in information sources, such as ACI and ICRI reports, company literature and guides, OSHA guidelines, and other government informational documents. ACI 503R is specifically noted as a general guideline for the safe handling of epoxy compounds.

4.3.3 *General handling hazards*—Thermosetting resins describe a generic family of products that includes unsaturated polyesters, vinyl esters, epoxy, and polyurethane resins. The materials used with them are generally described as hardeners, curing agents, peroxide initiators, isocyanates, fillers, and flexibilizers. There are precautions that should be observed when handling thermosetting resins and their component materials. Some general hazards that may be encountered when handling thermosetting resins are listed as follows:

- Skin irritation, such as burns, rashes, and itching;
- Skin sensitization, which is an allergic reaction similar to that caused by poison ivy, building insulation, or other allergens;
- Breathing organic vapors from cleaning solvents, monomers, and diluents;
- With a sufficient concentration in air, explosion or fire of flammable materials when exposed to heat, flames, pilot lights, sparks, static electricity, cigarettes, or other sources of ignition;
- Exothermic reactions of mixtures of materials causing fires or personal injury; and
- Nuisance dust caused by grinding or handling of the cured FRP materials (consult manufacturer's literature for specific hazards).

The complexity of thermosetting resins and associated materials makes it essential that labels and MSDS are read and understood by those working with these products. CFR 16, Part 1500, regulates the labeling of hazardous substances and includes thermosetting-resin materials. ANSI Z-129.1 provides further guidance regarding classification and precautions.

4.3.4 *Personnel safe handling and clothing*—Disposable suits and gloves are suitable for handling fiber and resin materials. Disposable rubber or plastic gloves are recommended and should be discarded after each use. Gloves should be resistant to resins and solvents.

Safety glasses or goggles should be used when handling resin components and solvents. Respiratory protection, such as dust masks or respirators, should be used when fiber fly, dust, or organic vapors are present, or during mixing and placing of resins if required by the FRP system manufacturer.

4.3.5 *Workplace safe handling*—The workplace should be well ventilated. Surfaces should be covered as needed to protect against contamination and resin spills. Each FRP system constituent material has different handling and storage requirements to prevent damage. Consult with the material manufacturer for guidance. Some resin systems are potentially dangerous during the mixing of the components. Consult the manufacturer's literature for proper mixing procedures and MSDSs for specific handling hazards. Ambient cure resin formulations produce heat when curing, which in turn accelerates the reaction. Uncontrolled reactions, including fuming, fire, or violent boiling, may occur in containers holding a mixed mass of resin; therefore, containers should be monitored.

4.3.6 *Clean-up and disposal*—Clean-up can involve use of flammable solvents, and appropriate precautions should be observed. Clean-up solvents are available that do not present the same flammability concerns. All waste materials should be contained and disposed of as prescribed by the prevailing environmental authority.

CHAPTER 5—INSTALLATION

Procedures for installing FRP systems have been developed by the system manufacturers and often differ between systems. In addition, installation procedures can vary within a system, depending on the type and condition of the structure. This chapter presents general guidelines for the installation of FRP systems. Contractors trained in accordance with the installation procedures developed by the system manufacturer should install FRP systems. Deviations from the procedures developed by the FRP system manufacturer should not be allowed without consulting with the manufacturer.

5.1—Contractor competency

The FRP system installation contractor should demonstrate competency for surface preparation and application of the FRP system to be installed. Contractor competency can be demonstrated by providing evidence of training and documentation of related work previously completed by the contractor or by actual surface preparation and installation of the FRP system on portions of the structure. The FRP system manufacturer or their authorized agent should train the contractor's application personnel in the installation procedures of their system and ensure they are competent to install the system.

5.2—Temperature, humidity, and moisture considerations

Temperature, relative humidity, and surface moisture at the time of installation can affect the performance of the FRP system. Conditions to be observed before and during installation include surface temperature of the concrete, air temperature, relative humidity, and corresponding dew point.

Primers, saturating resins, and adhesives generally should not be applied to cold or frozen surfaces. When the surface temperature of the concrete surface falls below a minimum level as specified by the FRP system manufacturer, improper saturation of the fibers and improper curing of the resin constituent materials can occur, compromising the integrity of the FRP system. An auxiliary heat source can be used to raise the ambient and surface temperature during installation. The heat source should be clean and not contaminate the surface or the uncured FRP system.

Resins and adhesives generally should not be applied to damp or wet surfaces unless they have been formulated for such applications. FRP systems should not be applied to concrete surfaces that are subject to moisture vapor transmission. The transmission of moisture vapor from a concrete surface through the uncured resin materials typically appears as surface bubbles and can compromise the bond between the FRP system and the substrate.

5.3—Equipment

Each FRP system has unique equipment designed specifically for the application of the materials for that system. This equipment can include resin impregnators, sprayers, lifting/positioning devices, and winding machines. All equipment should be clean and in good operating condition. The contractor should have personnel trained in the operation of all equipment. Personal protective equipment, such as gloves, masks, eye guards, and coveralls, should be chosen and worn for each employee's function. All supplies and equipment should be available in sufficient quantities to allow continuity in the installation project and quality assurance.

5.4—Substrate repair and surface preparation

The behavior of concrete members strengthened or retrofitted with FRP systems is highly dependent on a sound concrete substrate and proper preparation and profiling of the concrete surface. An improperly prepared surface can result in debonding or delamination of the FRP system before achieving the design load transfer. The general guidelines presented in this chapter should be applicable to all externally bonded FRP systems. Specific guidelines for a particular FRP system should be obtained from the FRP system manufacturer. Substrate preparation can generate noise, dust, and disruption to building occupants.

5.4.1 Substrate repair—All problems associated with the condition of the original concrete and the concrete substrate that can compromise the integrity of the FRP system should be addressed before surface preparation begins. ACI 546R and ICRI 03730 detail methods for the repair and surface preparation of concrete. All concrete repairs should meet the requirements of the design drawings and project specifications. The FRP system manufacturer should be consulted on the compatibility of the materials used for repairing the substrate with the FRP system.

5.4.1.1 *Corrosion-related deterioration*—Externally bonded FRP systems should not be applied to concrete substrates suspected of containing corroded reinforcing steel. The expansive forces associated with the corrosion process are difficult to determine and could compromise the structural integrity of the externally applied FRP system. The cause(s) of the corrosion should be addressed and the corrosion-related deterioration should be repaired before the application of any externally bonded FRP system.

5.4.1.2 *Injection of cracks*—Some FRP manufacturers have reported that the movement of cracks 0.010 in. (0.3 mm) and wider can affect the performance of the externally bonded FRP system through delamination or fiber crushing. Consequently, cracks wider than 0.010 in. (0.3 mm) should be pressure injected with epoxy in accordance with ACI 224.1R. Smaller cracks exposed to aggressive environments may require resin injection or sealing to prevent corrosion of existing steel reinforcement. Crack-width criteria for various exposure conditions are given in ACI 224R.

5.4.2 *Surface preparation*—Surface preparation requirements should be based on the intended application of the FRP system. Applications can be categorized as bond-critical or contact-critical. Bond-critical applications, such as flexural or shear strengthening of beams, slabs, columns, or walls, require an adhesive bond between the FRP system and the concrete. Contact-critical applications, such as confinement of columns, only require intimate contact between the FRP system and the concrete. Contact-critical applications do not require an adhesive bond between the FRP system and the concrete substrate, although one is often provided to facilitate installation.

5.4.2.1 *Bond-critical applications*—Surface preparation for bond-critical applications should be in accordance with recommendations of ACI 546R and ICRI 03730. The concrete or repaired surfaces to which the FRP system is to be applied should be freshly exposed and free of loose or unsound materials. Where fibers wrap around the corners of rectangular cross sections, the corners should be rounded to a minimum 1/2 in. (13 mm) radius to prevent stress concentrations in the FRP system and voids between the FRP system and the concrete. Roughened corners should be smoothed with putty. Obstructions, reentrant corners, concave surfaces, and embedded objects can affect the performance of the FRP system and should be addressed. Obstructions and embedded objects may need to be removed before installing the FRP system. Reentrant corners and concave surfaces may require special detailing to ensure that the bond of the FRP system to the substrate is maintained. Surface preparation can be accomplished using abrasive or water-blasting techniques. All laitance, dust, dirt, oil, curing compound, existing coatings, and any other matter that could interfere with the bond of the FRP system to the concrete should be removed. Bug holes and other small surface voids should be completely exposed during surface profiling. After the profiling operations are complete, the surface should be cleaned and protected before FRP installation so that no materials that can interfere with bond are redeposited on the surface.

The concrete surface should be prepared to a minimum concrete surface profile (CSP) 3 as defined by the ICRI-surface-profile chips. The FRP system manufacturer should be consulted to determine if more aggressive surface profiling is necessary. Localized out-of-plane variations, including form lines, should not exceed 1/32 in. (1 mm) or the tolerances recommended by the FRP system manufacturer. Localized out-of-plane variations can be removed by grinding before abrasive or water blasting or can be smoothed over using epoxy putty if the variations are very small. Bug holes and voids should be filled with epoxy putty.

All surfaces to receive the strengthening system should be as dry as recommended by the FRP system manufacturer. Water in the pores can inhibit resin penetration and reduce mechanical interlocking. Moisture content should be evaluated in accordance with the requirements of ACI 503.4.

5.4.2.2 *Contact-critical applications*—In applications involving confinement of structural concrete members, surface preparation should promote continuous intimate contact between the concrete surface and the FRP system. Surfaces to be wrapped should, at a minimum, be flat or convex to promote proper loading of the FRP system. Large voids in the surface should be patched with a repair material compatible with the existing concrete.

Materials with low compressive strength and elastic modulus, like plaster, can reduce the effectiveness of the FRP system and should be removed.

5.5—Mixing of resins

Mixing of resins should be done in accordance with the FRP system manufacturer's recommended procedure. All resin components should be at a proper temperature and mixed in the correct ratio until there is a uniform and complete mixing of components. Resin components are often contrasting colors, so full mixing is achieved when color streaks are eliminated.

Resins should be mixed for the prescribed mixing time and visually inspected for uniformity of color. The material manufacturer should supply recommended batch sizes, mixture ratios, mixing methods, and mixing times.

Mixing equipment can include small electrically powered mixing blades or specialty units, or resins can be mixed by hand stirring, if needed. Resin mixing should be in quantities sufficiently small to ensure that all mixed resin can be used within the resin's pot life. Mixed resin that exceeds its pot life should not be used because the viscosity will continue to increase and will adversely affect the resin's ability to penetrate the surface or saturate the fiber sheet.

5.6—Application of constituent materials

Fumes can accompany the application of some FRP resins. FRP systems should be selected with consideration for their impact on the environment, including emission of volatile organic compounds and toxicology.

5.6.1 *Primer and putty*—Where required, primer should be applied to all areas on the concrete surface where the FRP system is to be placed. The primer should be placed uniformly on the prepared surface at the manufacturer's specified rate of coverage. The applied primer should be protected from dust, moisture, and other contaminants prior to applying the FRP system.

Putty should be used in an appropriate thickness and sequence with the primer as recommended by the FRP manufacturer. The system-compatible putty, which is typically a thickened epoxy paste, should be used only to fill voids and smooth surface discontinuities before the application of other materials. Rough edges or trowel lines of cured putty should be ground smooth before continuing the installation.

Prior to applying the saturating resin or adhesive, the primer and putty should be allowed to cure as specified by the FRP system manufacturer. If the putty and primer are fully cured, additional surface preparation may be required prior to the application of the saturating resin or adhesive. Surface preparation requirements should be obtained from the FRP system manufacturer.

5.6.2 *Wet layup systems*—Wet layup FRP systems are typically installed by hand using dry fiber sheets and a saturating resin, and the manufacturer's recommendations should be followed. The saturating resin should be applied uniformly to all prepared surfaces where the system is to be placed. The fibers can also be impregnated in a separate process using a resin-impregnating machine before placement on the concrete surface.

The reinforcing fibers should be gently pressed into the uncured saturating resin in a manner recommended by the FRP system manufacturer. Entrapped air between layers should be released or rolled out before the resin sets. Sufficient saturating resin should be applied to achieve full saturation of the fibers.

Successive layers of saturating resin and fiber materials should be placed before the complete cure of the previous layer of resin. If previous layers are cured, interlayer surface preparation, such as light sanding or solvent application as recommended by the system manufacturer, may be required.

5.6.3 *Machine-applied systems*—Machine-applied systems can use resin-preimpregnated tow or dry-fiber tows. Prepreg tows are impregnated with saturating resin off-site and delivered to the work site as spools of prepreg tow material. Dry fibers are impregnated at the job site during the winding process.

Wrapping machines are primarily used for the automated wrapping of concrete columns. The tows can be wound either horizontally or at a specified angle. The wrapping machine is placed around the column and automatically wraps the tow material around the perimeter of the column while moving up and down the column.

After wrapping, prepreg systems should be cured at an elevated temperature. Usually a heat source is placed around the column for a predetermined temperature and time schedule in accordance with the manufacturer's recommendations. Temperatures are controlled to ensure consistent quality. The resulting FRP jackets do not have any seams or welds because the tows are continuous. In all of the previous application steps, the FRP system manufacturer's recommendations should be followed.

5.6.4 *Precured systems*—Precured systems include shells, strips, and open grid forms that are typically installed with an adhesive. Adhesives should be uniformly applied to the prepared surfaces where precured systems are to be placed, except in certain instances of concrete confinement where adhesion of the FRP system to the concrete substrate may not be required.

Precured laminate surfaces to be bonded should be clean and prepared in accordance with the manufacturer's recommendation. The precured sheets or curved shells should be placed on or into the wet adhesive in a manner recommended by the FRP manufacturer. Entrapped air between layers should be released or rolled out before the adhesive sets. Adhesive should be applied at a rate recommended by the FRP manufacturer to ensure full bonding of successive layers.

5.6.5 *Protective coatings*—Coatings should be compatible with the FRP strengthening system and applied in accordance with the manufacturer's recommendations. Typically, the use of solvents to clean the FRP surface prior to installing coatings is not recommended due to the deleterious effects solvents can have on the polymer resins. The FRP system manufacturer should approve any use of solvent-wipe preparation of FRP surfaces before the application of protective coatings.

The coatings should be periodically inspected and maintenance should be provided to ensure the effectiveness of the coatings.

5.7—Alignment of FRP materials

The FRP-ply orientation and ply-stacking sequence should be specified. Small variations in angle, as little as 5 degrees, from the intended direction of fiber alignment can cause a substantial reduction in strengthening. Deviations in ply orientation should only be made if approved by the engineer.

Sheet and fabric materials should be handled in a manner to maintain the fiber straightness and orientation. Fabric kinks, folds, or other forms of severe waviness should be reported to the engineer.

5.8—Multiple plies and lap splices

Multiple plies can be used, provided all plies are fully impregnated with the resin system, the resin shear strength is sufficient to transfer the shearing load between plies, and the bond strength between the concrete and FRP system is sufficient. For long spans, multiple lengths of fiber material or precured stock can be used to continuously transfer the load by providing adequate lap splices. Lap splices should be staggered, unless noted otherwise by the engineer. Lap splice details, including lap length, should be based on testing and installed in accordance with the manufacturer's recommendations. Due to the unique characteristics of some FRP systems, multiple plies and lap splices are not always possible. Specific guidelines on lap splices are given in Chapter 12.

5.9—Curing of resins

Curing of resins is a time-temperature-dependent phenomenon. Ambient-cure resins can take several days to reach full cure. Temperature extremes or fluctuations can retard or accelerate the resin curing time. The FRP system manufacturer may offer several prequalified grades of resin to accommodate these situations.

Elevated cure systems require the resin to be heated to a specific temperature for a specified period of time. Various combinations of time and temperature within a defined envelope should provide full cure of the system.

All resins should be cured according to the manufacturer's recommendation. Field modification of resin chemistry should not be permitted.

Cure of installed plies should be monitored before placing subsequent plies. Installation of successive layers should be halted if there is a curing anomaly.

5.10—Temporary protection

Adverse temperatures; direct contact by rain, dust, or dirt; excessive sunlight; high humidity; or vandalism can damage an FRP system during installation and cause improper cure of the resins. Temporary protection, such as tents and plastic screens, may be required during installation and until the resins have cured. If temporary shoring is required, the FRP system should be fully cured before removing the shoring and allowing the structural member to carry the design loads. In the event of suspected damage to the FRP system during installation, the engineer should be notified and the FRP system manufacturer consulted.

CHAPTER 6—INSPECTION, EVALUATION, AND ACCEPTANCE

Quality-assurance and quality-control (QA/QC) programs and criteria are to be maintained by the FRP system manufacturers, the installation contractors, and others associated with the project. The quality-control program should be comprehensive and cover all aspects of the strengthening project. The degree of quality control and the scope of testing, inspection, and record keeping depends on the size and complexity of the project.

Quality assurance is achieved through a set of inspections and applicable tests to document the acceptability of the installation. Project specifications should include a requirement to provide a quality-assurance plan for the installation and curing of all FRP materials. The plan should include personnel safety issues, application and inspection of the FRP system, location and placement of splices, curing provisions, means to ensure dry surfaces, quality-assurance samples, cleanup, and the required submittals listed in Section 13.3.

6.1—Inspection

FRP systems and all associated work should be inspected as required by the applicable codes. In the absence of such requirements, inspection should be conducted by or under the supervision of a licensed engineer or a qualified inspector. Inspectors should be knowledgeable of FRP systems and be trained in the installation of FRP systems. The qualified inspector should require compliance with the design drawings and project specifications. During the installation of the FRP system, daily inspection should be conducted and should include:

- Date and time of installation;
- Ambient temperature, relative humidity, and general weather observations;
- Surface temperature of concrete;
- Surface dryness per ACI 503.4;
- Surface preparation methods and resulting profile using the ICRI-surface-profile-chips;
- Qualitative description of surface cleanliness;
- Type of auxiliary heat source, if applicable;
- Widths of cracks not injected with epoxy;
- Fiber or precured laminate batch number(s) and approximate location in structure;
- Batch numbers, mixture ratios, mixing times, and qualitative descriptions of the appearance of all mixed resins, including primers, putties, saturants, adhesives, and coatings mixed for the day;
- Observations of progress of cure of resins;
- Conformance with installation procedures;
- Pull-off test results: bond strength, failure mode, and location;
- FRP properties from tests of field sample panels or witness panels, if required;
- Location and size of any delaminations or air voids; and
- General progress of work.

The inspector should provide the engineer or owner with the inspection records and witness panels. It is recommended that the records and witness panels be retained for a minimum of 10 years or a period specified by the engineer. The installation contractor should retain sample cups of mixed resin and maintain a record of the placement of each batch.

6.2—Evaluation and acceptance

FRP systems should be evaluated and accepted/rejected based on conformance/nonconformance with the design drawings and specifications. FRP system material properties, installation within specified placement tolerances, presence of delaminations, cure of resins, and adhesion to substrate should be included in the evaluation. Placement tolerances including fiber orientation, cured thickness, ply orientation, width and spacing, corner radii, and lap splice lengths should be evaluated.

Witness panel and pulloff tests are used to evaluate the installed FRP system. In-place load testing can also be used to confirm the installed behavior of the FRP strengthened member (Nanni and Gold 1998).

6.2.1 *Materials*—Before starting the project, the FRP system manufacturer should submit certification of specified material properties and identification of all materials to be used. Additional material testing can be conducted if deemed necessary based on the complexity and intricacy of the project. Evaluation of delivered FRP materials can include tests for tensile strength, infrared spectrum analysis, T_g, gel time, pot life, and adhesive shear strength. These tests are usually performed on material samples sent to a laboratory, according to the quality-control test plan. Tests for pot life of resins and curing hardness are usually conducted on-site.

Materials that do not meet the minimum requirements as specified by the engineer should be rejected.

Witness panels can be used to evaluate the tensile strength and modulus, lap splice strength, hardness, and T_g of the FRP system installed and cured on-site using installation procedures similar to those used to install and cure the FRP system. During installation, flat panels of predetermined dimensions and thickness can be fabricated on-site according to a predetermined sampling plan. After curing on-site, the panels can then be sent to a laboratory for testing. Witness panels can be retained or submitted to an approved laboratory in a timely manner for testing of strength, hardness, and T_g. Strength and elastic modulus of FRP materials can be determined in accordance with ASTM D 3039 and ISIS (1998). The properties to be evaluated by testing should be specified. The engineer may waive or alter the frequency of testing.

Some FRP systems, including precured and machine-wound systems, do not lend themselves to the fabrication of small, flat, witness panels. For these cases, the engineer can modify the requirements to include test panels or samples provided by the manufacturer. Tension strength and elastic modulus, lap-splice strength of FRP materials can also be determined using burst testing of field fabricated ring specimens (ISIS 1998).

During installation, sample cups of mixed resin should be prepared according to a predetermined sampling plan and retained for testing to determine the level of cure (see Section 6.2.4).

6.2.2 *Fiber orientation*—Fiber or precured-laminate orientation should be evaluated by visual inspection. Fiber waviness—a localized appearance of fibers that deviate from the general straight-fiber line in the form of kinks or waves—should be evaluated for wet layup systems.

Fiber or precured laminate misalignment of more than 5 degrees from that specified on the design drawings (approximately 1 in./ft [80 mm/m]) should be reported to the engineer for evaluation and acceptance.

6.2.3 *Delaminations*—The cured FRP system should be evaluated for delaminations or air voids between multiple plies or between the FRP system and the concrete. Inspection methods should be capable of detecting delaminations of 2 in.^{2} (1300 mm^2) or greater. Methods such as acoustic sounding (hammer sounding), ultrasonics, and thermography can be used to detect delaminations.

The effect of delaminations or other anomalies on the structural integrity and durability of the FRP system should be evaluated. Delamination size, location, and quantity relative to the overall application area should be considered in the evaluation.

General acceptance guidelines for wet layup systems are:

- Small delaminations less than 2 in.^{2} each (1300 mm^2) are permissible as long as the delaminated area is less than 5% of the total laminate area and there are no more than 10 such delaminations per 10 ft^2 (1 m^2);
- Large delaminations, greater than 25 in.^{2} (16,000 mm^2), can affect the performance of the installed FRP and should be repaired by selectively cutting away the affected sheet and applying an overlapping sheet patch of equivalent plies; and
- Delaminations less than 25 in.^{2} (16,000 mm^2). may be repaired by resin injection or ply replacement, depending on the size and number of delaminations and their locations.

For precured FRP systems, each delamination should be evaluated and repaired in accordance with the engineer's direction. Upon completion of the repairs, the laminate should be re-inspected to verify that the repair was properly accomplished.

6.2.4 *Cure of resins*—The relative cure of FRP systems can be evaluated by laboratory testing of witness panels or resin-cup samples using ASTM D 3418. The relative cure of the resin can also be evaluated on the project site by physical observation of resin tackiness and hardness of work surfaces or hardness of retained resin samples. The FRP system manufacturer should be consulted to determine the specific resin-cure verification requirements. For precured systems, adhesive-hardness measurements should be made in accordance with the manufacturer's recommendation.

6.2.5 *Adhesion strength*—For bond-critical applications, tension adhesion testing of cored samples should be conducted using the methods in ACI 503R or ASTM D 4541 or the method described by ISIS (1998). The sampling frequency should be specified. Tension adhesion strengths should exceed 200 psi (1.4 MPa) and exhibit failure of the concrete substrate. Lower strengths or failure between the FRP system and the concrete or between plies should be reported to the engineer for evaluation and acceptance.

6.2.6 *Cured thickness*—Small core samples, typically 0.5 in. (13 mm) diameter, may be taken to visually ascertain the cured laminate thickness or number of plies. Cored samples required for adhesion testing also can be used to ascertain the laminate thickness or number of plies. The sampling frequency should be specified. Taking samples from high-stress areas or splice areas should be avoided. For aesthetic reasons, the cored hole can be filled and smoothed with a repair mortar or the FRP system putty. If required, a 4 to 8 in. (100 to 200 mm) overlapping FRP sheet patch of equivalent plies may be applied over the filled and smoothed core hole immediately after taking the core sample. The FRP sheet patch should be installed in accordance with the manufacturer's installation procedures.

CHAPTER 7—MAINTENANCE AND REPAIR

7.1—General

As with any strengthening or retrofit repair, the owner should periodically inspect and assess the performance of the FRP system used for strengthening or retrofit repair of concrete members. The causes of any damage or deficiencies detected during routine inspections should be identified and addressed before performing any repairs or maintenance.

7.2—Inspection and assessment

7.2.1 *General inspection*—A visual inspection looks for changes in color, debonding, peeling, blistering, cracking, crazing, deflections, indications of reinforcing-bar corrosion, and other anomalies. In addition, ultra-sonic, acoustic sounding (hammer tap), or thermographic tests may indicate signs of progressive delamination.

7.2.2 *Testing*—Testing can include pull-off tension tests (Section 6.2.5) or conventional structural loading tests.

7.2.3 *Assessment*—Test data and observations are used to assess any damage and the structural integrity of the strengthening system. The assessment can include a recommendation for repairing any deficiencies and preventing recurrence of degradation.

7.3—Repair of strengthening system

The method of repair of the strengthening system depends on the causes of the damage, the type of material, the form of degradation, and the level of damage. Repairs to the FRP system should not be undertaken without first identifying and addressing the causes of the damage.

Minor damage should be repaired, including localized FRP laminate cracking or abrasions that affect the structural integrity of the laminate. Minor damage can be repaired by bonding FRP patches over the damaged area. The FRP patches should possess the same characteristics, such as thickness or ply orientation, as the original laminate. The FRP patches should be installed in accordance with the material manufacturer's recommendation. Minor delaminations can be repaired by epoxy-resin injection. Major damage, including peeling and debonding of large areas, may require removal of the affected area, reconditioning of the cover concrete, and replacing the FRP laminate.

7.4—Repair of surface coating

In the event that the surface-protective coating should be replaced, the FRP laminate should be inspected for structural damage or deterioration. The surface coating may be replaced using a process approved by the system manufacturer.

PART 4—DESIGN RECOMMENDATIONS

CHAPTER 8—GENERAL DESIGN CONSIDERATIONS

General design recommendations are presented in this chapter. The recommendations presented are based on the traditional reinforced concrete design principles stated in the requirements of ACI 318-99 and knowledge of the specific mechanical behavior of FRP reinforcement.

FRP strengthening systems should be designed to resist tensile forces while maintaining strain compatibility between the FRP and the concrete substrate. FRP reinforcement should not be relied upon to resist compressive forces. It is acceptable, however, for FRP tension reinforcement to experience compression due to moment reversals or changes in load pattern. The compressive strength of the FRP reinforcement, however, should be neglected.

8.1—Design philosophy

These design recommendations are based on limit-states-design principles. This approach sets acceptable levels of safety against the occurrence of both serviceability limit states (excessive deflections, cracking) and ultimate-limit states (failure, stress rupture, fatigue). In assessing the nominal strength of a member, the possible failure modes and subsequent strains and stresses in each material should be assessed. For evaluating the serviceability of a member, engineering principles, such as modular ratios and transformed sections, can be used.

FRP strengthening systems should be designed in accordance with ACI 318-99 strength and serviceability requirements, using the load factors stated in ACI 318-99. The strength-reduction factors required by ACI 318-99 should also be used. Additional reduction factors applied to the contribution of the FRP reinforcement are recommended by this guide to reflect lesser existing knowledge of FRP systems compared with reinforced and prestressed concrete. The engineer may wish to incorporate more conservative strength-reduction factors if there are uncertainties regarding existing material strengths or substrate conditions greater than those discussed in these recommendations.

For the design of FRP systems for the seismic retrofit of a structure, it may be appropriate to use capacity design principles (Paulay and Priestley 1992), which assume a structure should develop its full capacity and require that members be capable of resisting the associated required shear strengths. These FRP systems, particularly when used for columns, should be designed to provide seismic resistance through energy dissipation and deflection capacity at the code-defined base shear levels. Unless additional performance objectives are specified by the owner, life safety is the primary performance objective of seismic designs with an allowance for some level of structural damage to provide energy dissipation. Consequently, retrofitted members may require some level of repair or replacement following a seismic event. Caution should be exercised upon re-entering a seismically damaged structure especially during or after a subsequent fire.

8.2—Strengthening limits

Careful consideration should be given to determine reasonable strengthening limits. These limits are imposed to guard against collapse of the structure should bond or other failure of the FRP system occur due to fire, vandalism, or other causes. Some designers and system manufacturers have recommended that the unstrengthened structural member, without FRP reinforcement, should have sufficient strength to resist a certain level of load. Using this philosophy, in the event that the FRP system is damaged, the structure will still be capable of resisting a reasonable level of load without collapse. It is the recommendation of the committee that the existing strength of the structure be sufficient to resist a level of load as described by Eq. (8-1).

$$(\phi R_n)_{existing} \geq (1.2S_{DL} + 0.85S_{LL})_{new} \tag{8-1}$$

More specific limits for structures requiring a fire endurance rating are given in Section 8.2.1.

8.2.1 *Structural fire endurance*—The level of strengthening that can be achieved through the use of externally bonded FRP reinforcement is often limited by the code-required fire-resistance rating of a structure. The polymer resins used in wet layup and prepreg FRP systems and the polymer adhesives used in precured FRP systems lose structural integrity at temperatures exceeding the glass transition temperature T_g of the polymer. While the glass transition temperature can vary depending on the polymer chemistry, a typical range for field-applied resins and adhesives is 140 to 180 °F (60 to 82 °C). Due to the high temperatures associated with a fire and the low temperature resistance of the FRP system, the FRP system will not be capable of enduring a fire for any appreciable amount of time. Furthermore, it is most often not feasible to insulate the FRP system to substantially increase its fire endurance because the amount of insulation that would be required to protect the FRP system is far more than can be realistically applied.

Although the FRP system itself has a low fire endurance, combination of the FRP system with an existing concrete structure may still have an adequate level of fire endurance. This is attributable to the inherent fire endurance of the existing concrete structure alone. To investigate the fire endurance of an FRP-strengthened concrete structure, it is important to recognize that the strength of traditional reinforced concrete structures is somewhat reduced during exposure to the high temperatures associated with a fire event as well. The yield strength of reinforcing steel is reduced, and the compressive strength of concrete is reduced. As a result, the overall resistance of a reinforced concrete member to load effects is reduced. This concept is used in ACI 216R to provide a method of computing the fire endurance of concrete members. ACI 216R suggests limits that maintain a reasonable level of safety against complete collapse of the structure in the event of a fire.

By extending the concepts established in ACI 216R to FRP-strengthened reinforced concrete, limits on strengthening can be used to ensure a strengthened structure will not collapse in a fire. A member's resistance to load effects, with reduced steel and concrete strengths and without the strength of the FRP reinforcement, can be computed. This resistance can then be compared with the load demand on the member to ensure the structure will not collapse under service loads and elevated temperatures.

The existing strength of a structural member with a fire-resistance rating should satisfy the conditions of Eq. (8-2) if it is to be strengthened with an FRP system. The load effects, S_{DL} and S_{LL}, should be determined using the current load requirements for the structure. If the FRP system is meant to allow greater load-carrying strength, such as an increase in live load, the load effects should be computed using these greater loads.

$$(R_{n\theta})_{existing} \geq S_{DL} + S_{LL} \tag{8-2}$$

The nominal resistance of the member at an elevated temperature $R_{n\theta}$ can be determined using the guidelines outlined in ACI 216R. This resistance should be computed for the time period required by the structure's fire-resistance rating—for example, a two-hour fire rating—and should disallow the contribution of the FRP system. Furthermore, if the FRP system is meant to address a loss in strength, such as deterioration, the resistance should reflect this loss.

The fire endurance of FRP materials can be improved through the use of certain polymers or methods of fire protection. Although these methods are typically impractical, these methods may become more effective in the future. If such methods can be shown through testing to increase the fire endurance of the FRP system to meet the fire resistance rating of a building structure, the criteria put forth in Eq. (8-2) can be modified to reflect the level of protection provided. The tests of these systems should, however, use end-point criteria defined by reaching the glass transition temperature of the polymer. That is, the fire endurance of the FRP system should be set to the measured amount of time required for the polymer resins or adhesives in the FRP system to reach their glass transition temperature under exposure to a fire. ASTM E 119 gives guidance on the types of fires (heats and durations) to be used in such tests.

8.2.2 *Overall structural strength*—While FRP systems are effective in strengthening members for flexure and shear and providing additional confinement, other modes of failure, such as punching shear and bearing capacity of footings, may be unaffected by FRP systems. It is important to ensure that all members of a structure are capable of withstanding the anticipated increase in loads associated with the strengthened members.

Additionally, analysis should be performed on the member strengthened by the FRP system to check that under overload conditions the strengthened member will fail in a flexure mode rather than in a shear mode.

8.2.3 *Seismic applications*—The majority of research into seismic strengthening of structures has dealt with strengthening of columns. FRP systems are used to confine columns to improve concrete compressive strength, reduce required splice length, and increase the shear strength (Priestley et al. 1996). Limited information is available for strengthening building frames in seismic zones. Chapter 11 identifies restrictions on the use of FRP for shear and flexural strengthening in seismic conditions.

When beams or floors in building frames in seismic risk Zones 3 and 4 are strengthened, the strength and stiffness of both the beam/floor and column should be checked to ensure the formation of the plastic hinge away from the column and the joint (Mosallam et al. 2000).

8.3—Selection of FRP systems

8.3.1 *Environmental considerations*—Environmental conditions uniquely affect resins and fibers of various FRP systems. The mechanical properties (for example, tensile strength, strain, and elastic modulus) of some FRP systems degrade under exposure to certain environments, such as alkalinity, salt water, chemicals, ultraviolet light, high temperatures, high humidity, and freezing and thawing cycles. The material properties used in design should account for this degradation in accordance with Section 8.4.

The engineer should select an FRP system based on the known behavior of that system in the anticipated service conditions. Some important environmental considerations that relate to the nature of the specific systems are given as follows. Specific information can be obtained from the FRP system manufacturer.

- **Alkalinity/acidity:** The performance of an FRP system over time in an alkaline or acidic environment depends on the matrix material and the reinforcing fiber. Dry, unsaturated bare, or unprotected carbon fiber is resistant to both alkaline and acidic environments, while bare glass fiber can degrade over time in these environments. A properly applied resin matrix, however, should isolate and protect the fiber from the alkaline/acidic environment and retard deterioration. The FRP system selected should include a resin matrix resistant to alkaline and acidic environments. Sites with high alkalinity and high moisture or relative humidity favor the selection of carbon-fiber systems over glass-fiber systems.
- **Thermal expansion:** FRP systems may have thermal expansion properties that are different from those of concrete. In addition, the thermal expansion properties of the fiber and polymer constituents of an FRP system can vary. Carbon fibers have a coefficient of thermal expansion near zero while glass fibers have a coefficient of thermal expansion similar to concrete. The polymers used in FRP strengthening systems typically have coefficients of thermal expansion roughly five times that of concrete. Calculation of thermally induced strain differentials are complicated by variations in fiber orientation, fiber volume fraction (ratio of the volume of fibers to the volume of fibers and resins in an FRP), and thickness of adhesive layers. Experience (Motavalli et al. 1993; Soudki and Green 1997;

Table 8.1—Environmental-reduction factor for various FRP systems and exposure conditions

Exposure conditions	Fiber and resin type	Environmental-reduction factor C_E
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment (chemical plants and waste water treatment plants)	Carbon/epoxy	0.85
	Glass/epoxy	0.50
	Aramid/epoxy	0.70

Green et al. 1998) indicates, however, that thermal expansion differences do not affect bond for small ranges of temperature change, such as ±50 °F (±28 °C).

- **Electrical conductivity:** GFRP and AFRP are effective electrical insulators, while CFRP is conductive. To avoid potential galvanic corrosion of steel elements, carbon-based FRP materials should not come in direct contact with steel.

8.3.2 *Loading considerations*—Loading conditions uniquely affect different fibers of FRP systems. The engineer should select an FRP system based on the known behavior of that system in the anticipated service conditions.

Some important loading considerations that relate to the nature of the specific systems are given below. Specific information should be obtained from material manufacturers.

- **Impact tolerance:** AFRP and GFRP systems demonstrate better tolerance to impact than CFRP systems; and
- **Creep-rupture and fatigue:** CFRP systems are highly resistive to creep-rupture under sustained loading and fatigue failure under cyclic loading. GFRP systems are more sensitive to both loading conditions.

8.3.3 *Durability considerations*—Durability of FRP systems is the subject of considerable ongoing research (Steckel et al. 1999a). The engineer should select an FRP system that has undergone durability testing consistent with the application environment. Durability testing may include hot-wet cycling, alkaline immersion, freeze-thaw cycling, and ultraviolet exposure.

Any FRP system that completely encases or covers a concrete section should be investigated for the effects of a variety of environmental conditions including those of freeze/thaw, steel corrosion, alkali and silica aggregate reactions, water entrapment, vapor pressures, and moisture vapor transmission (Soudki and Green 1997; Christensen et al. 1996; Toutanji 1999). Many FRP systems create a moisture-impermeable layer on the surface of the concrete. In areas where moisture vapor transmission is expected, adequate means should be provided to allow moisture to escape the concrete structure.

8.3.4 *Protective-coating selection considerations*—A coating can be applied to the installed FRP system to protect it from exposure to certain environmental conditions. The thickness and type of coating should be selected based on the requirements of the composite repair; resistance to environmental effects, such as moisture, salt water, temperature extremes, fire, impact, and UV exposure; resistance to site specific effects; and resistance to vandalism. Coatings are relied upon to retard the degradation of the mechanical properties of the FRP systems. The coatings should be periodically inspected and maintenance should be provided to ensure the effectiveness of the coatings.

External coatings or thickened coats of resin over fibers can protect them from damage due to impact or abrasion. In high-impact or traffic areas, additional levels of protection may be necessary. Portland-cement plaster and polymer coatings are commonly used for protection where minor impact or abrasion is anticipated.

8.4—Design material properties

Unless otherwise stated, the material properties reported by manufacturers, such as the ultimate tensile strength, typically do not consider long-term exposure to environmental conditions and should be considered as initial properties. Because long-term exposure to various types of environments can reduce the tensile properties and creep-rupture and fatigue endurance of FRP laminates, the material properties used in design equations should be reduced based on the environmental exposure condition.

Equations (8-3) through (8-5) give the tensile properties that should be used in all design equations. The design ultimate tensile strength should be determined using the environmental-reduction factor given in Table 8.1 for the appropriate fiber type and exposure condition.

$$f_{fu} = C_E f_{fu}^* \tag{8-3}$$

Similarly, the design rupture strain should also be reduced for environmental-exposure conditions.

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \tag{8-4}$$

Because FRP materials are linearly elastic until failure, the design modulus of elasticity can then be determined from Hooke's law. The expression for the modulus of elasticity, given in Eq. (8-5), recognizes that the modulus is typically unaffected by environmental conditions. The modulus given in this equation will be the same as the initial value reported by the manufacturer.

$$E_f = \frac{f_{fu}}{\varepsilon_{fu}} \tag{8-5}$$

The constituent materials, fibers, and resins of an FRP system affect its durability and resistance to environmental exposure. The environmental-reduction factors given in Table 8.1 are conservative estimates based on the relative durability of each fiber type. As more research information is developed and becomes available, these values will be refined. The methodology regarding the use of these factors, however, will remain unchanged. Durability test data for FRP systems with and without protective coatings may be obtained from the manufacturer of the FRP system under consideration.

As Table 8.1 illustrates, if the FRP system is located in a relatively benign environment, such as indoors, the reduction factor is closer to unity. If the FRP system is located in an aggressive environment where prolonged exposure to high humidity, freeze-thaw cycles, salt water, or alkalinity is expected, a lower reduction factor should be used. The reduction factor can reflect the use of a protective coating if the coating has been shown through testing to lessen the effects of environmental exposure and the coating is maintained for the life of the FRP system.

CHAPTER 9—FLEXURAL STRENGTHENING

Bonding FRP reinforcement to the tension face of a concrete flexural member with fibers oriented along the length of the member will provide an increase in flexural strength. Increases in overall flexural strength from 10 to 160% have been documented (Meier and Kaiser 1991; Ritchie et al. 1991; Sharif et al. 1994). When taking into account ductility and serviceability limits, however, increases of 5 to 40% are more reasonable.

This chapter does not apply to FRP systems used to enhance the flexural strength of members in the expected plastic hinge regions of ductile moment frames resisting seismic loads. The design of such applications, if used, should examine the behavior of the strengthened frame, considering the strengthened sections have a much-reduced rotation and curvature capacities. In this case, the effect of cyclic load reversal on the FRP reinforcement should be investigated.

9.1—General considerations

This chapter presents guidance on the calculation of the flexural strengthening effect of adding longitudinal FRP reinforcement to the tension face of a reinforced concrete member. A specific illustration of the concepts in this chapter applied to strengthening existing rectangular sections reinforced in the tension zone with nonprestressed steel is given. The general concepts outlined here can, however, be extended to nonrectangular shapes (T-sections and I-sections) and to members with compression steel reinforcement. In the case of prestressed members, strain compatibility, with respect to the state of strain in the stressed member, should be used to evaluate the FRP contribution. Additional failure modes controlled by rupture of prestressing tendons should also be considered.

9.1.1 *Assumptions*—The following assumptions are made in calculating the flexural resistance of a section strengthened with an externally applied FRP system:

- Design calculations are based on the actual dimensions, internal reinforcing steel arrangement, and material properties of the existing member being strengthened;
- The strains in the reinforcement and concrete are directly proportional to the distance from the neutral axis, that is, a plane section before loading remains plane after loading;
- There is no relative slip between external FRP reinforcement and the concrete;
- The shear deformation within the adhesive layer is neglected since the adhesive layer is very thin with slight variations in its thickness;
- The maximum usable compressive strain in the concrete is 0.003;
- The tensile strength of concrete is neglected; and
- The FRP reinforcement has a linear elastic stress-strain relationship to failure.

It should be understood that while some of these assumptions are necessary for the sake of computational ease, the assumptions do not accurately reflect the true fundamental behavior of FRP flexural reinforcement. For example, there will be shear deformation in the adhesive layer causing relative slip between the FRP and the substrate. The inaccuracy of the assumptions will not, however, significantly affect the computed flexural strength of an FRP-strengthened member. An additional strength reduction factor (presented in Section 9.2) will conservatively compensate for any such discrepancies.

9.1.2 *Section shear strength*—When FRP reinforcement is being used to increase the flexural strength of a member, it is important to verify that the member will be capable of resisting the shear forces associated with the increased flexural strength. The potential for shear failure of the section should be considered by comparing the design shear strength of the section to the required shear strength. If additional shear strength is required, FRP laminates oriented transversely to the section can be used to resist shear forces as described in Chapter 10.

9.1.3 *Existing substrate strain*—Unless all loads on a member, including self-weight and any prestressing forces, are removed before installation of FRP reinforcement, the substrate to which the FRP is applied will be strained. These strains should be considered as initial strains and should be excluded from the strain in the FRP (Arduini and Nanni 1997; Nanni et al. 1998). The initial strain level on the bonded substrate ε_{bi} can be determined from an elastic analysis of the existing member, considering all loads that will be on the member, during the installation of the FRP system. It is recommended that the elastic analysis of the existing member be based on cracked section properties.

9.2—Nominal strength

The strength-design approach requires that the design flexural strength of a member exceed its required moment strength as indicated by Eq. (9-1). Design flexural strength ϕM_n refers to the nominal strength of the member multiplied by a strength-reduction factor, and the required moment strength M_u refers to the load effects calculated from factored loads (for example, $\alpha_{DL} M_{DL} + \alpha_{LL} M_{LL} + ...$). This guide recommends that required moment strength of a section be calculated by use of load factors as required by ACI 318-99. Furthermore, this guide recommends the use of the strength reduction factors ϕ required by ACI 318-99 with an additional strength reduction factor of 0.85 applied to the flexural contribution of the FRP reinforcement alone ($\psi_f = 0.85$). See Eq. (9-2) for an illustration of the use of the additional reduction factor. This additional reduction factor is meant to account for lower reliability of the FRP reinforcement, as compared with internal steel reinforcement.

$$\phi M_n \geq M_u \qquad (9\text{-}1)$$

The nominal flexural strength of an FRP-strengthened concrete member can be determined based on strain compatibility, internal force equilibrium, and the controlling mode of failure.

9.2.1 *Failure modes*—The flexural strength of a section depends on the controlling failure mode. The following flexural failure modes should be investigated for an FRP-strengthened section (GangaRao and Vijay 1998):

- Crushing of the concrete in compression before yielding of the reinforcing steel;
- Yielding of the steel in tension followed by rupture of the FRP laminate;
- Yielding of the steel in tension followed by concrete crushing;
- Shear/tension delamination of the concrete cover (cover delamination); and
- Debonding of the FRP from the concrete substrate

(FRP debonding).

Concrete crushing is assumed to occur if the compressive strain in the concrete reaches its maximum usable strain ($\varepsilon_c = \varepsilon_{cu} = 0.003$). Rupture of the FRP laminate is assumed to occur if the strain in the FRP reaches its design rupture strain ($\varepsilon_f = \varepsilon_{fu}$) before the concrete reaches its maximum usable strain.

Cover delamination or FRP debonding can occur if the force in the FRP cannot be sustained by the substrate. In order to prevent debonding of the FRP laminate, a limitation should be placed on the strain level developed in the laminate. Eq. (9-2) gives an expression for a bond-dependent coefficient κ_m.

$$\kappa_m = \begin{cases} \dfrac{1}{60\varepsilon_{fu}}\left(1 - \dfrac{nE_f t_f}{2{,}000{,}000}\right) \le 0.90 \text{ for } nE_f t_f \le 1{,}000{,}000 \\ \dfrac{1}{60\varepsilon_{fu}}\left(\dfrac{500{,}000}{nE_f t_f}\right) \le 0.90 \text{ for } nE_f t_f > 1{,}000{,}000 \end{cases} \tag{9-2) U.S.}$$

$$\kappa_m = \begin{cases} \dfrac{1}{60\varepsilon_{fu}}\left(1 - \dfrac{nE_f t_f}{360{,}000}\right) \le 0.90 \text{ for } nE_f t_f \le \ 180{,}000 \\ \dfrac{1}{60\varepsilon_{fu}}\left(\dfrac{90{,}000}{nE_f t_f}\right) \le 0.90 \text{ for } nE_f t_f > \ 180{,}000 \end{cases} \tag{9-2) SI}$$

The term κ_m, expressed in Eq. (9-2), is a factor no greater than 0.90 that may be multiplied by the rupture strain of the FRP laminate to arrive at a strain limitation to prevent debonding. The number of plies n used in this equation is the number of plies of FRP flexural reinforcement at the location along the length of the member where the moment strength is being computed. This term recognizes that laminates with greater stiffnesses are more prone to delamination. Thus, as the stiffness of the laminate increases, the strain limitation becomes more severe. For laminates with a unit stiffness $nE_f t_f$ greater than 1,000,000 lb/in. (180,000 N/mm), κ_m limits the force in the laminate as opposed to the strain level. This effectively places an upper bound on the total force that can be developed in an FRP laminate, regardless of the number of plies. The width of the FRP laminate is not included in the calculation of the unit stiffness, $nE_f t_f$, because an increase in the width of the FRP results in a proportional increase in the bond area.

The κ_m term is only based on a general recognized trend and on the experience of engineers practicing the design of bonded FRP systems. Further research into the mechanics of bond of FRP flexural reinforcement should result in more accurate methods for predicting delamination, resulting in refinement of Eq. (9-2). Further development of the equation will likely account not only for the stiffness of the laminate but also for the stiffness of the member to which the laminate is bonded. In the interim, the committee recommends the use of Eq. (9-2) to limit the strain in the FRP and prevent delamination.

9.2.2 *Strain level in FRP reinforcement*—It is important to determine the strain level in the FRP reinforcement at the ultimate-limit state. Because FRP materials are linearly elastic until failure, the level of strain in the FRP will dictate the level of stress developed in the FRP. The maximum strain level that can be achieved in the FRP reinforcement will be governed by either the strain level developed in the FRP at the point at which concrete crushes, the point at which the FRP ruptures, or the point at which the FRP debonds from the substrate. This maximum strain or the effective strain level in the FRP reinforcement at the ultimate-limit state can be found from Eq. (9-3).

$$\varepsilon_{fe} = \varepsilon_{cu}\left(\frac{h-c}{c}\right) - \varepsilon_{bi} \le \kappa_m \varepsilon_{fu} \tag{9-3}$$

where ε_{bi} is the initial substrate strain as described in Section 9.1.3.

9.2.3 *Stress level in the FRP reinforcement*—The effective stress level in the FRP reinforcement is the maximum level of stress that can be developed in the FRP reinforcement before flexural failure of the section. This effective stress level can be found from the strain level in the FRP, assuming perfectly elastic behavior.

$$f_{fe} = E_f \varepsilon_{fe} \tag{9-4}$$

9.3—Ductility

The use of externally bonded FRP reinforcement for flexural strengthening will reduce the ductility of the original member. In some cases, the loss of ductility is negligible. Sections that experience a significant loss in ductility, however, should be addressed. To maintain a sufficient degree of ductility, the strain level in the steel at the ultimate-limit state should be checked. Adequate ductility is achieved if the strain in the steel at the point of concrete crushing or failure of the FRP, including delamination or debonding, is at least 0.005, according to the definition of a tension-controlled section as given in Chapter 2 of ACI 318-99.

The approach taken by this guide follows the philosophy of ACI 318-99 Appendix B, where a section with low ductility should compensate with a higher reserve of strength. The higher reserve of strength is achieved by applying a strength-reduction factor of 0.70 to brittle sections, as opposed to 0.90 for ductile sections.

Therefore, a strength-reduction factor given by Eq. (9-5) should be used, where ε_s is the strain in the steel at the ultimate-limit state.

$$\phi = \begin{cases} 0.90 & \text{for } \varepsilon_s \ge 0.005 \\ 0.70 + \dfrac{0.20(\varepsilon_s - \varepsilon_{sy})}{0.005 - \varepsilon_{sy}} & \text{for } \varepsilon_{sy} < \varepsilon_s < 0.005 \\ 0.70 & \text{for } \varepsilon_s \le \varepsilon_{sy} \end{cases} \tag{9-5}$$

This equation sets the reduction factor at 0.90 for ductile sections and 0.70 for brittle sections where the steel does not yield, and provides a linear transition for the reduction factor between these two extremes (Fig. 9.1).

9.4—Serviceability

The serviceability of a member (deflections, crack widths) under service loads should satisfy applicable provisions of ACI 318-99. The effect of the FRP external reinforcement on the serviceability can be assessed using the transformed section analysis.

To avoid inelastic deformations of the reinforced concrete members strengthened with external FRP reinforcement, the

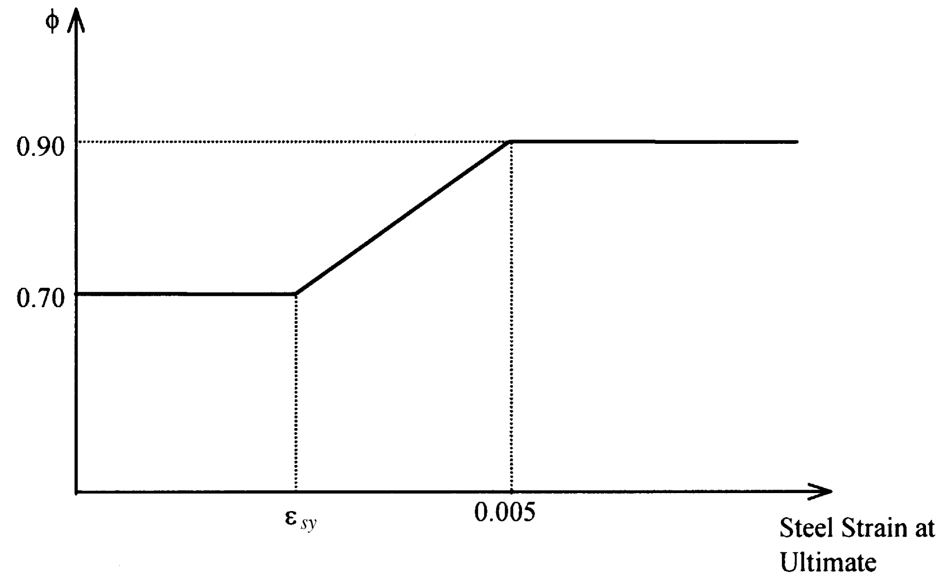

Fig. 9.1—Graphical representation of the strength-reduction factor as a function of the ductility.

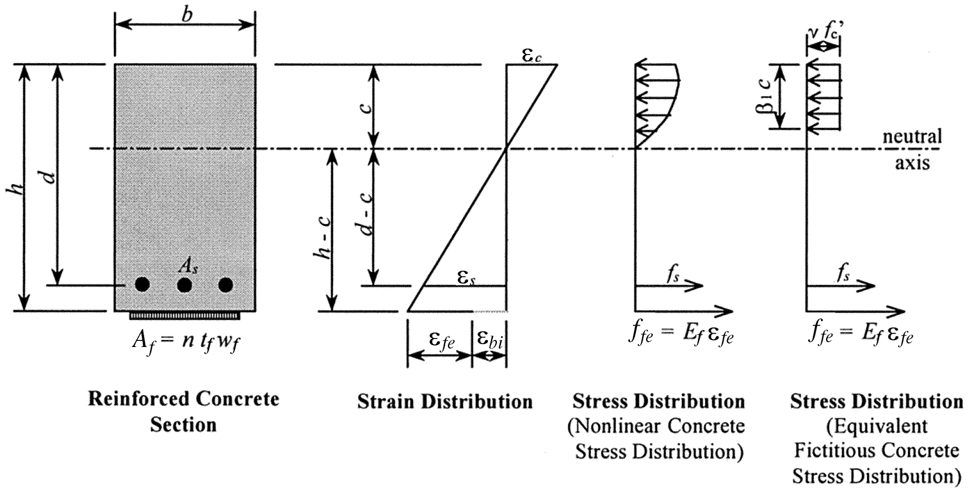

Fig. 9.2—Internal strain and stress distribution for a rectangular section under flexure at ultimate stage.

existing internal steel reinforcement should be prevented from yielding under service load levels. The stress in the steel under service load should be limited to 80% of the yield strength, as shown in Eq. (9-6).

$$f_{s,s} \le 0.80 f_y \tag{9-6}$$

9.5—Creep-rupture and fatigue stress limits

To avoid creep-rupture of the FRP reinforcement under sustained stresses or failure due to cyclic stresses and fatigue of the FRP reinforcement, the stress levels in the FRP reinforcement under these stress conditions should be checked. Because these stress levels will be within the elastic response range of the member, the stresses can be computed by use of an elastic analysis.

In Section 3.4, the creep-rupture phenomenon and fatigue characteristics of FRP material were described and the resistance to its effects by various types of fibers was examined. As stated in Section 3.4.1, research has indicated that glass, aramid, and carbon fibers can sustain 0.30, 0.47, and 0.91 times their ultimate strengths, respectively, before encountering a creep-rupture problem (Yamaguchi et al. 1997). To avoid failure of an FRP-reinforced member due to creep-rupture and fatigue of the FRP, stress limits for these conditions should be imposed on the FRP reinforcement. The stress level in the FRP reinforcement can be computed using an elastic analysis and an applied moment due to all sustained loads (dead loads and the sustained portion of the live load) plus the maximum moment induced in a fatigue loading cycle (Fig. 9.2). The sustained stress should be limited as expressed by Eq. (9-7) to maintain safety. Values for safe sustained plus cyclic stress levels are given in Table 9.1. These values are based on the stress limits previously stated in Section 3.4.1 with an imposed safety factor of 1/0.60.

$$\text{Sustained plus cyclic stress limit} \ge f_{f,s} \tag{9-7}$$

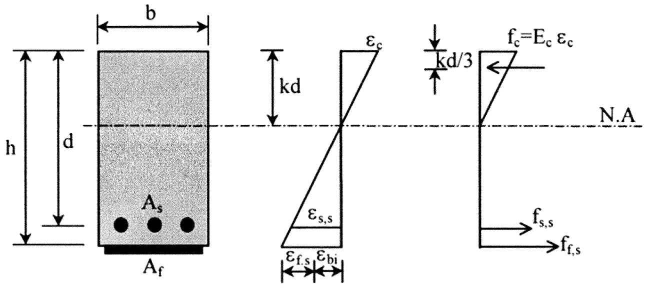

Fig. 9.3—Elastic strain and stress distribution.

Table 9.1—Sustained plus cyclic service load stress limits in FRP reinforcement

	Fiber type		
Stress type	Glass FRP	Aramid FRP	Carbon FRP
Sustained plus cyclic stress limit	$0.20f_{fu}$	$0.30f_{fu}$	$0.55f_{fu}$

9.6—Application to a singly reinforced rectangular section

To illustrate the concepts presented in this chapter, this section describes the application of these concepts to a singly reinforced rectangular section (nonprestressed).

9.6.1 *Ultimate strength*—Figure 9.2 illustrates the internal strain and stress distribution for a rectangular section under flexure at the ultimate limit state.

The calculation procedure used to arrive at the ultimate strength should satisfy strain compatibility and force equilibrium and should consider the governing mode of failure. Several calculation procedures can be derived to satisfy these conditions. The calculation procedure described herein is one such procedure that illustrates a trial and error method.

The trial and error procedure involves selecting an assumed depth to the neutral axis, c; calculating the strain level in each material using strain compatibility; calculating the associated stress level in each material; and checking internal force equilibrium. If the internal force resultants do not equilibrate, the depth to the neutral axis must be revised and the procedure repeated.

For any assumed depth to the neutral axis c, the strain level in the FRP reinforcement can be computed from Eq. (9-3) presented in section 9.2.2 and reprinted as follows for convenience. This equation considers the governing mode of failure for the assumed neutral axis depth. If the first term in the equation controls, concrete crushing controls flexural failure of the section. If the second term controls, FRP failure (rupture or debonding) controls flexural failure of the section.

$$\varepsilon_{fe} = \varepsilon_{cu}\left(\frac{h-c}{c}\right) - \varepsilon_{bi} \le \kappa_m\varepsilon_{fu} \qquad (9\text{-}3)$$

The effective stress level in the FRP reinforcement can be found from the strain level in the FRP, assuming perfectly elastic behavior.

$$f_{fe} = E_f\varepsilon_{fe} \qquad (9\text{-}4)$$

Based on the strain level in the FRP reinforcement, the strain level in the nonprestressed tension steel can be found from Eq. (9-8) using strain compatibility.

$$\varepsilon_s = (\varepsilon_{fe} + \varepsilon_{bi})\left(\frac{d-c}{h-c}\right) \qquad (9\text{-}8)$$

The stress in the steel is calculated from the strain level in the steel assuming elastic-plastic behavior.

$$f_s = E_s\varepsilon_s \le f_y \qquad (9\text{-}9)$$

With the strain and stress level in the FRP and steel reinforcement determined for the assumed neutral axis depth, internal force equilibrium may be checked using Eq. (9-10).

$$c = \frac{A_sf_s + A_ff_{fe}}{\gamma f_c'\beta_1 b} \qquad (9\text{-}10)$$

The terms γ and β_1 in Eq. (9-10) are parameters defining a rectangular stress block in the concrete equivalent to the actual nonlinear distribution of stress. If concrete crushing is the controlling mode of failure (before or after steel yielding), γ and β_1 can be taken as the values associated with the Whitney stress block ($\gamma = 0.85$ and β_1 from Section 10.2.7.3 of ACI 318-99). If FRP rupture, cover delamination, or FRP-debonding control failure occur, the Whitney stress block will give reasonably accurate results. A more accurate stress block for the actual strain level reached in the concrete at the ultimate-limit state may be used. Moreover, methods considering a nonlinear stress distribution in the concrete can also be used.

The actual depth to the neutral axis, c, is found by simultaneously satisfying Eq. (9-3), (9-4), (9-8), (9-9) and (9-10), thus establishing internal force equilibrium and strain compatibility.

The nominal flexural strength of the section with FRP external reinforcement can be computed from Eq. (9-11). An additional reduction factor ψ_f is applied to the flexural-strength contribution of the FRP reinforcement. A factor ψ_f = 0.85 is recommended.

$$M_n = A_sf_s\left(d - \frac{\beta_1c}{2}\right) + \psi_fA_ff_{fe}\left(h - \frac{\beta_1c}{2}\right) \qquad (9\text{-}11)$$

9.6.2 *Stress in steel under service loads*—The stress level in the steel reinforcement can be calculated based on a cracked elastic analysis of the strengthened reinforced concrete section, as indicated by Eq. (9-12).

$$f_{s,s} = \frac{\left[M_s + \varepsilon_{bi}A_fE_f\left(h - \frac{kd}{3}\right)\right](d-kd)E_s}{A_sE_s\left(d - \frac{kd}{3}\right)(d-kd) + A_fE_f\left(h - \frac{kd}{3}\right)(h-kd)} \qquad (9\text{-}12)$$

The distribution of strain and stress in the reinforced concrete section is shown in Fig. 9.3. Similar to conventional reinforced concrete, the depth to the neutral axis at service kd can be computed by taking the first moment of the areas of the transformed section. The transformed area of the FRP may

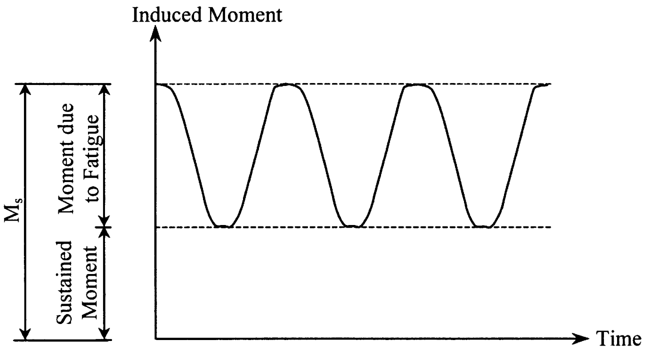

Fig. 9.4—Illustration of the level of applied moment to be used to check the stress limits in the FRP reinforcement.

be obtained by multiplying the area of FRP by the modular ratio of FRP to concrete. Although this method ignores the difference in the initial strain level of the FRP, the initial strain level does not greatly influence the depth to the neutral axis in the elastic response range of the member.

The stress in the steel under service loads computed from Eq. (9-12) should be compared against the limits described in Section 9.4.

9.6.3 *Stress in FRP under service loads*—The stress level in the FRP reinforcement can be computed using Eq. (9-13) with $f_{s,s}$ from Eq. (9-12) and M_s (in Eq. (9-12)) equal to the moment due to all sustained loads (dead loads and the sustained portion of the live load) plus the maximum moment induced in a fatigue loading cycle as shown in Fig. 9.4. Equation (9-13) gives the stress level in the FRP reinforcement under an applied moment within the elastic response range of the member.

$$f_{f,s} = f_{s,s}\left(\frac{E_f}{E_s}\right)\frac{h-kd}{d-kd} - \varepsilon_{bi}E_f \qquad (9\text{-}13)$$

The stress in the FRP under service loads computed from Eq. (9-13) should be compared against the limits described in Section 9.5.

CHAPTER 10—SHEAR STRENGTHENING

FRP systems have been shown to increase the shear strength of existing concrete beams and columns by wrapping or partially wrapping the members (Malvar et al. 1995; Chajes et al. 1995; Norris et al. 1997; Kachlakev and McCurry 2000). Orienting the fibers transverse to the axis of the member or perpendicular to potential shear cracks is effective in providing additional shear strength (Sato et al. 1996). Increasing the shear strength can also result in flexural failures, which are relatively more ductile in nature as compared to shear failures.

10.1—General considerations

This chapter presents guidance on the calculation of the shear-strengthening effect of adding FRP shear reinforcement to a reinforced concrete beam or column. The additional shear strength that can be provided by the FRP system is based on many factors, including geometry of beam or column, wrapping scheme, and existing concrete strength, but should always be limited in accordance with the provisions of Chapter 8.

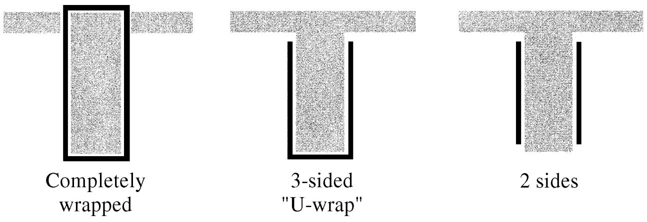

Fig. 10.1—Typical wrapping schemes for shear strengthening using FRP laminates.

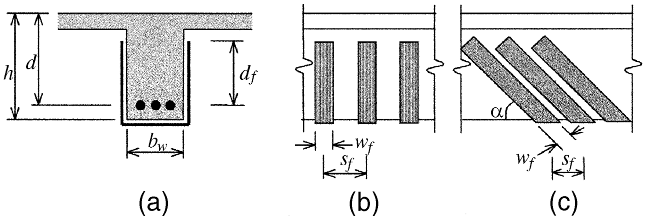

Fig. 10.2—Illustration of the dimensional variables used in shear-strengthening calculations for repair, retrofit, or strengthening using FRP laminates.

Shear strengthening using external FRP may be provided at locations of expected plastic hinges or stress reversal and for enhancing postyield flexural behavior of members in moment frames resisting seismic loads only by completely wrapping the section. For external FRP reinforcement in the form of discrete strips, the center-to-center spacing between the strips should not exceed the sum of $d/4$ plus the width of the strip.

10.2—Wrapping schemes

The three types of FRP wrapping schemes used to increase the shear strength of prismatic, rectangular beams, or columns are illustrated in Fig. 10.1. Completely wrapping the FRP system around the section on all four sides is the most efficient wrapping scheme and is most commonly used in column applications where access to all four sides of the column is usually available. In beam applications, where an integral slab makes it impractical to completely wrap the member, the shear strength can be improved by wrapping the FRP system around three sides of the member (U-wrap) or bonding to the two sides of the member.

Although all three techniques have been shown to improve the shear strength of a member, completely wrapping the section is the most efficient, followed by the three-sided U-wrap. Bonding to two sides of a beam is the least efficient scheme.

In all wrapping schemes, the FRP system can be installed continuously along the span length of a member or placed as discrete strips. As discussed in Section 8.3.3, consideration should be given to the use of continuous FRP reinforcement that completely encases the member and may prevent the migration of moisture.

10.3—Nominal shear strength

The nominal shear strength of a concrete member strengthened with an FRP system should exceed the required shear strength (Eq. (10-1)). The required shear strength on an FRP-strengthened concrete member should be computed with the load factors required by ACI 318-99. The shear strength should be calculated using the strength-reduction factor ϕ, required by ACI 318-99.

Table 10.1—Recommended additional reduction factors for FRP shear reinforcement

$\psi_f = 0.95$	Completely wrapped members
$\psi_f = 0.85$	Three-sided U-wraps or bonded face piles

$$\phi V_n \geq V_u \tag{10-1}$$

The nominal shear strength of an FRP-strengthened concrete member can be determined by adding the contribution of the FRP reinforcing to the contributions from the reinforcing steel (stirrups, ties, or spirals) and the concrete (Eq. (10-2)). An additional reduction factor ψ_f is applied to the contribution of the FRP system.

$$\phi V_n = \phi(V_c + V_s + \psi_f V_f) \tag{10-2}$$

It is suggested that an additional reduction factor y_f be applied to the shear contribution of the FRP reinforcement. For bond-critical shear reinforcement, an additional reduction factor of 0.85 is recommended. For contact-critical shear reinforcement, an additional reduction factor of 0.95 is recommended. These recommendations are given in Table 10.1.

10.4—FRP system contribution to shear strength

Figure 10.2 illustrates the dimensional variables used in shear-strengthening calculations for FRP laminates. The contribution of the FRP system to shear strength of a member is based on the fiber orientation and an assumed crack pattern (Khalifa et al. 1998). The shear strength provided by the FRP reinforcement can be determined by calculating the force resulting from the tensile stress in the FRP across the assumed crack. The shear contribution of the FRP shear reinforcement is then given by Eq. (10-3).

$$V_f = \frac{A_{fv} f_{fe} (\sin\alpha + \cos\alpha) d_f}{s_f} \tag{10-3}$$

where

$$A_{fv} = 2nt_f w_f \tag{10-4}$$

The tensile stress in the FRP shear reinforcement at ultimate is directly proportional to the level of strain that can be developed in the FRP shear reinforcement at ultimate.

$$f_{fe} = \varepsilon_{fe} E_f \tag{10-5}$$

10.4.1 *Effective strain in FRP laminates*—The effective strain is the maximum strain that can be achieved in the FRP system at the ultimate load stage and is governed by the failure mode of the FRP system and of the strengthened reinforced concrete member. The engineer should consider all possible failure modes and use an effective strain representative of the critical failure mode. The following subsections give guidance on determining this effective strain for different configurations of FRP laminates used for shear strengthening of reinforced concrete members.

10.4.1.1 *Completely wrapped members*—For reinforced concrete column and beam members completely wrapped by the FRP system, loss of aggregate interlock of the concrete has been observed to occur at fiber strains less than the ultimate fiber strain. To preclude this mode of failure, the maximum strain used for design should be limited to 0.4% for applications that can be completely wrapped with the FRP system (Eq. [10-6(a)]).

$$\varepsilon_{fe} = 0.004 \leq 0.75\varepsilon_{fu} \tag{10-6(a)}$$

(for completely wrapping around the member's cross section)

This strain limitation is based on testing (Priestley et al. 1996) and experience. Higher strains should not be used for FRP shear-strengthening applications.

10.4.1.2 *Bonded U-wraps or bonded face plies*—FRP systems that do not enclose the entire section (two- and three-sided wraps) have been observed to delaminate from the concrete before the loss of aggregate interlock of the section. For this reason, bond stresses should be analyzed to determine the usefulness of these systems and the effective strain level that can be achieved (Triantafillou 1998a). The effective strain is calculated using a bond-reduction coefficient κ_v applicable to shear.

$$\varepsilon_{fe} = \kappa_v \varepsilon_{fu} \leq 0.004 \tag{10-6(b)}$$

(for U-wraps or bonding to two sides)

The bond-reduction coefficient is a function of the concrete strength, the type of wrapping scheme used, and the stiffness of the laminate. The bond-reduction coefficient can be computed from Eq. (10-7) through (10-10) (Khalifa et al. 1998).

$$\kappa_v = \frac{k_1 k_2 L_e}{468\varepsilon_{fu}} \leq 0.75 \tag*{(10-7) U.S.}$$

$$\kappa_v = \frac{k_1 k_2 L_e}{11{,}900\varepsilon_{fu}} \leq 0.75 \tag*{(10-7) SI}$$

The active bond length L_e is the length over which the majority of the bond stress is maintained. This length is given by Eq. (10-8).

$$L_e = \frac{2500}{(nt_f E_f)^{0.58}} \tag*{(10-8) U.S.}$$

$$L_e = \frac{23{,}300}{(nt_f E_f)^{0.58}} \tag*{(10-8) SI}$$

The bond-reduction coefficient also relies on two modification factors, k_1 and k_2, that account for the concrete strength and the type of wrapping scheme used, respectively. Expressions for these modification factors are given in Eq. (10-9) and (10-10).

$$k_1 = \left(\frac{f_c'}{4000}\right)^{2/3} \tag*{(10-9) U.S.}$$

$$k_1 = \left(\frac{f_c'}{27}\right)^{2/3} \tag*{(10-9) SI}$$

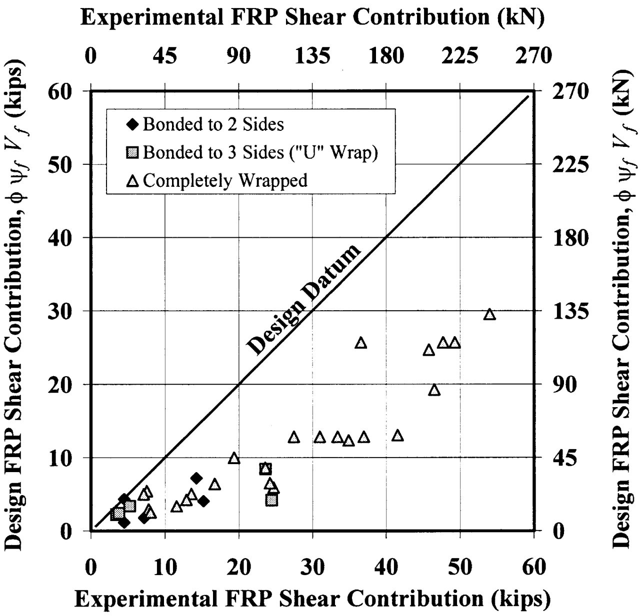

Fig. 10.3—Comparison of experimental results to the results using the design procedure presented.

$$k_2 = \begin{cases} \dfrac{d_f - L_e}{d_f} & \text{for U-wraps} \\[2ex] \dfrac{d_f - 2L_e}{d_f} & \text{for two sides bonded} \end{cases} \qquad (10\text{-}10)$$

The methodology for determining κ_v has been validated for members in regions of high shear and low moment, such as monotonically loaded simply supported beams. Although the methodology has not been confirmed for shear strengthening in areas subjected to combined high flexural and shear stresses or in regions where the web is primarily in compression (negative moment regions), κ_v is suggested to be sufficiently conservative for such cases.

The design procedures outlined herein have been developed by a combination of analytical and empirical results. The design methodology has been compared to the results of many researchers in Fig. 10.3 (Khalifa et al. 1998).

Mechanical anchorages can be used at termination points to develop larger tensile forces (Khalifa et al. 1999). The effectiveness of such mechanical anchorages, along with the level of tensile stress they can develop, should be substantiated through representative physical testing. In no case, however, should the effective strain in FRP laminates exceed 0.004.

10.4.2 *Spacing*—Spaced FRP strips used for shear strengthening should be investigated to evaluate their contribution to the shear strength. Spacing should adhere to the limits as set by ACI 318-99 for internal steel shear reinforcement. The spacing of FRP strips is defined as the distance between the centerline of the strips. Structural testing should validate the use of discretely spaced FRP stirrups for shear strengthening (Hutchinson et al. 1998).

10.4.3 *Reinforcement limits*—The total shear reinforcement should be taken as the sum of the contribution of the FRP shear reinforcement and the steel shear reinforcement. The total shear reinforcement should be limited based on the criteria given for steel alone in ACI 318-99 Section 11.5.6.9. This limit is stated in Eq. (10-11).

$$V_s + V_f \le 8\sqrt{f_c'}\,b_w d \qquad (10\text{-}11)\ \text{U.S.}$$

$$V_s + V_f \le 0.66\sqrt{f_c'}\,b_w d \qquad (10\text{-}11)\ \text{SI}$$

CHAPTER 11—AXIAL COMPRESSION, TENSION, AND DUCTILITY ENHANCEMENT

Wrapping FRP systems completely around certain types of compression members will confine those members, leading to increases in axial compression strengths. Bonding FRP systems to concrete members can also increase the axial tension strength of the member. Confinement is also used to enhance the ductility of members subjected to combined axial and bending forces.

11.1—Axial compression

FRP systems can be used to increase the axial compression strength of a concrete member by providing confinement with an FRP jacket (Nanni and Bradford 1995, Toutanji 1999). Confining a concrete member is accomplished by orienting the fibers transverse to the longitudinal axis of the member. In this orientation, the hoop fibers are similar to conventional spiral or tie reinforcing steel. Any contribution of longitudinally aligned fibers to the axial compression strength of a concrete member should be neglected.

Confinement results in an increase in the apparent strength of the concrete and in the maximum usable compressive strain in the concrete (Seible et al. 1997). FRP jackets provide passive confinement to the compression member, remaining unstressed until dilation and cracking of the wrapped compression member occur. For this reason, intimate contact between the FRP jacket and the concrete member is critical.

The axial compressive strength of a nonslender, normal-weight concrete member confined with an FRP jacket may be calculated using the confined concrete strength (Eq. (11-1)). For nonseismic applications, the increase in axial strength should be limited in accordance with Section 11.1.2. Vertical displacement, section dilation, cracking, and strain limitations in the FRP jacket can also limit the amount of additional compression strength that can be achieved with an FRP jacket. The axial demand on an FRP-strengthened concrete member should be computed with the load factors required by ACI 318-99 and the axial compression strength should be calculated using the strength-reduction factors ϕ for spiral and tied members required by ACI 318-99.

For nonprestressed members with existing steel spiral reinforcement:

$$\phi P_n = 0.85\phi[0.85\psi_f f_{cc}'(A_g - A_{st}) + f_y A_{st}] \qquad (11\text{-}1(\text{a}))$$

For nonprestressed members with existing steel-tie reinforcement:

$$\phi P_n = 0.80\phi[0.85\psi_f f_{cc}'(A_g - A_{st}) + f_y A_{st}] \qquad (11\text{-}1(\text{b}))$$

It is recommended to take the additional reduction factor, $\psi_f = 0.95$. The apparent confined concrete strength for a circular concrete member wrapped with an FRP jacket providing a confining pressure f_l can be found from Eq. (11-2) (Mander et al. 1988) originally developed for confinement provided by steel jackets.

$$f'_{cc} = f'_c\left[2.25\sqrt{1+7.9\frac{f_l}{f'_c}} - 2\frac{f_l}{f'_c} - 1.25\right] \qquad (11\text{-}2)$$

Because Eq. (11-2) was originally developed for confinement provided by steel jackets, it is important to note that this model originally considered a constant confining pressure corresponding to the yield stress of the steel. This equation has been shown to be applicable to FRP-confined concrete (Spoelstra and Monti 1999). The confining pressure, however, must be considered to be linearly variable such that an increase in the strain in the FRP jacket results in a proportional increase in the confining pressure. To determine the full stress-strain behavior of FRP-confined concrete, the compressive strain in the concrete (longitudinal strain) must be related to the strain developed in the FRP jacket (transverse strain). The strain in the FRP jacket may then be used to determine the confining pressure and the resulting increase in the compressive stress in the concrete. A simpler approach may be used to determine the peak value of confined concrete stress or the confined concrete strength. The confined concrete strength can be computed from Eq. (11-2) using a confining pressure given in Eq. (11-3) that is the result of the maximum effective strain that can be achieved in the FRP jacket.

$$f_l = \frac{\kappa_a \rho_f f_{fe}}{2} = \frac{\kappa_a \rho_f \varepsilon_{fe} E_f}{2} \qquad (11\text{-}3)$$

If the member is subjected to combined compression and shear, the effective strain in the FRP jacket should be limited based on the criteria given in Eq. (11-4).

$$\varepsilon_{fe} = 0.004 \le 0.75\varepsilon_{fu} \qquad (11\text{-}4)$$

11.1.1 *Circular sections*—FRP jackets are most effective at confining circular members. The FRP system provides a circumferentially uniform confining pressure to the radial expansion of the compression member when the fibers are aligned transverse to the longitudinal axis of the member. The confining pressure provided by an FRP jacket installed around a circular member with a diameter h can be found using the reinforcement ratio given in Eq. (11-5).

$$\rho_f = \frac{4nt_f}{h} \qquad (11\text{-}5)$$

The efficiency factor κ_a for circular sections can be taken as equal to 1.0.

11.1.2 *Noncircular sections*—Testing has shown that confining square and rectangular members with FRP jackets can provide marginal increases in the axial compression strength of the member. Given the many unknowns with this type of application, there are no recommendations provided at this time on the use of FRP. Applications of this nature should be closely scrutinized and evaluated. In no case should FRP jackets with fibers running longitudinally be relied upon to resist compression.

11.1.3 *Serviceability considerations*—At load levels near ultimate, damage to the concrete in the form of significant cracking in the radial direction might occur. The FRP jacket contains the damage and maintains the structural integrity of the column. At service load levels, however, this type of damage should be avoided. In this way, the FRP jacket will only act during overloads that are temporary in nature.

To ensure that radial cracking will not occur under service loads, the transverse strain in the concrete should remain below its cracking strain at service load levels. This corresponds to limiting the stress in the concrete to $0.65f'_c$. In addition, the stress in the steel should remain below $0.60f_y$ to avoid plastic deformation under sustained or cyclic loads. By maintaining the specified stress in the concrete at service, the stress in the FRP jacket will be relatively low. The jacket is only stressed to significant levels when the concrete is transversely strained above the cracking strain and the rate of the transverse expansion becomes large. Because FRP jackets provide passive confinement, service load stresses in the FRP jacket should never exceed the creep-rupture stress limit.

In addition, axial deformations under service loads should be investigated to evaluate their effect on the performance of the structural member.

11.2—Tensile strengthening

FRP systems can be used to provide additional tensile strength to a concrete member. Due to the linear-elastic nature of FRP materials, the tensile contribution of the FRP system is directly related to its strain level and is calculated using Hooke's Law.

The level of tension provided by the FRP is limited by the design tensile strength of the FRP and the ability to transfer stresses into the substrate through bond (Nanni et al. 1997). The effective strain in the FRP can be determined based on the criteria given for shear strengthening in Eq. (10-6) through (10-9). The value of k_1 in Eq. (10-7) can be taken as 1.0. A minimum bond length of $2L_e$ (where L_e is the active bond length defined previously in Eq. (10-8)) should be provided to develop this level of strain.

11.3—Ductility

Increased ductility of a section results from the ability to develop greater compressive strains in the concrete before compressive failure (Seible et al. 1997). The FRP jacket can also serve to delay buckling of longitudinal steel reinforcement in compression, and to clamp lap splices of longitudinal steel reinforcement.

For seismic applications, FRP jackets should be designed to provide a confining stress sufficient to develop concrete compression strains associated with the displacement demands. The maximum usable compressive strain in concrete for FRP-confined circular reinforced concrete members can be found by use of Eq. (11-6) (Mander et al. 1988).

$$\varepsilon'_{cc} = \frac{1.71(5f'_{cc} - 4f'_c)}{E_c} \qquad (11\text{-}6)$$

Shear forces should also be evaluated in accordance with Chapter 10 to prevent brittle shear failure in accordance with ACI 318-99.

11.3.1 *Circular members*—The maximum usable compressive strain for an FRP-confined circular member can be found from Eq. (11-6) with f'_{cc} from Eq. (11-2) to (11-5) and using $\kappa_a = 1.0$.

11.3.2 *Noncircular members*—Confining square and rectangular sections, while not effective in increasing axial strength, is effective in improving the ductility of compression members. The maximum usable compressive strain for an FRP-confined square or rectangular member can be found from Eq. (11-6) with f'_{cc} from Eq. (11-2) to (11-4). The reinforcement ratio for rectangular sections can be found from Eq. (11-7).

$$\rho_f = \frac{2nt_f(b+h)}{bh} \qquad (11\text{-}7)$$

The efficiency factor for square and rectangular sections should be determined based on geometry, aspect ratio, and the configuration of steel reinforcement. Equation (11-8) can be used to determine this efficiency factor (Restrepo and DeVino 1996), where r is the radius of the edges of the section as described in the general guidelines of Chapter 12.

$$\kappa_a = 1 - \frac{(b-2r)^2 + (h-2r)^2}{3bh(1-\rho_g)} \qquad (11\text{-}8)$$

The confining effect of FRP jackets should be assumed to be negligible for rectangular sections with aspect ratios b/h exceeding 1.5, or face dimensions, b or h, exceeding 36 in. (900 mm), unless testing demonstrates their effectiveness.

CHAPTER 12—REINFORCEMENT DETAILS

This chapter offers guidance for detailing externally bonded FRP reinforcement. Detailing will typically depend on the geometry of the structure, the soundness and quality of the substrate, and the levels of load that are to be sustained by the FRP sheets or laminates. Many bond-related failures can be avoided by following these general guidelines for detailing FRP sheets or laminates:

- Do not turn inside corners;
- Provide a minimum 1/2 in. (13 mm) radius when the sheet is wrapped around outside corners; and
- Provide sufficient overlap when splicing FRP plies.

12.1—Bond and delamination

The actual distribution of bond stress in an FRP laminate is complicated by cracking of the substrate concrete. The general elastic distribution of interfacial shear stress and normal stress along an FRP laminate bonded to uncracked concrete is shown in Fig. 12.1. The normal stress is normal with respect to the plane of the FRP laminate.

For an FRP system installed according to Part 3 of this guide, the weak link in the concrete/FRP interface is the concrete. The soundness and tensile strength of the concrete substrate will limit the overall effectiveness of the bonded FRP system.

12.1.1 *FRP debonding*—Debonding of a properly installed FRP laminate can result from a lack of bonded area of the FRP laminate to the concrete substrate. The concrete cannot maintain the interfacial shear and normal stresses, and the FRP laminate debonds from the substrate with a relatively thin layer of concrete attached to it.

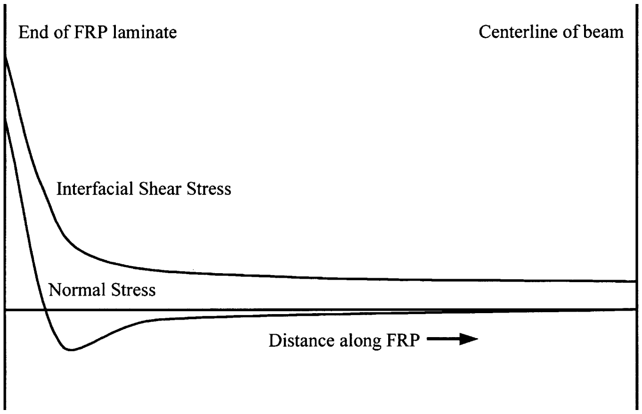

Fig. 12.1—Conceptual interfacial shear and normal stress distributions along the length of a bonded FRP laminate (Roberts and Haji-Kazemi 1989; Malek et al. 1998).

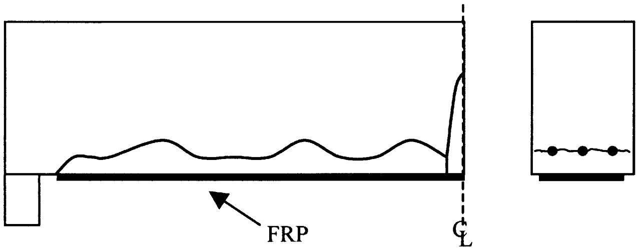

Fig. 12.2—Delamination caused by tension failure of the concrete cover.

The interface bond area should be calculated based on the horizontal shear and tensile strength of the concrete substrate. Because interface delamination or interface bond failure modes are brittle, using a bond strength reduction factor of 0.50 is recommended. Analytical methods for computing the bond stress are available (Blaschko et al. 1998; Brosens and Van Gemert 1997; Maeda et al. 1997).

Mechanical anchorages can be effective in increasing stress transfer (Khalifa et al. 1999). The performance of any anchorage system should be substantiated through testing.

12.1.2 *Concrete cover delamination*—Concrete cover delamination can also result from the normal stresses developed in a bonded FRP laminate. With this type of delamination, the existing internal reinforcing steel essentially acts as a bond breaker in a horizontal plane, and the reduced area of bulk concrete pulls away from the rest of the beam (this may be exacerbated if epoxy-coated steel reinforcement was used in the existing member). The result is the entire concrete cover layer splitting at the level of the tensile reinforcement from the rest of the reinforced concrete member (Fig. 12.2).

The tensile concrete cover splitting failure mode is controlled, in part, by the level of stress at the termination point of the FRP laminate. Instead of a more detailed analysis, the following general guidelines for the location of cut-off points for the FRP laminate can be used to avoid this type of failure:

- For simply supported beams, the plies should extend a distance d past the point along the span corresponding to the cracking moment M_{cr} under factored loads. In addition, if the factored shear force at the termination point is greater than 2/3 the concrete shear strength ($V_u > 0.67V_c$), the FRP laminates should be anchored

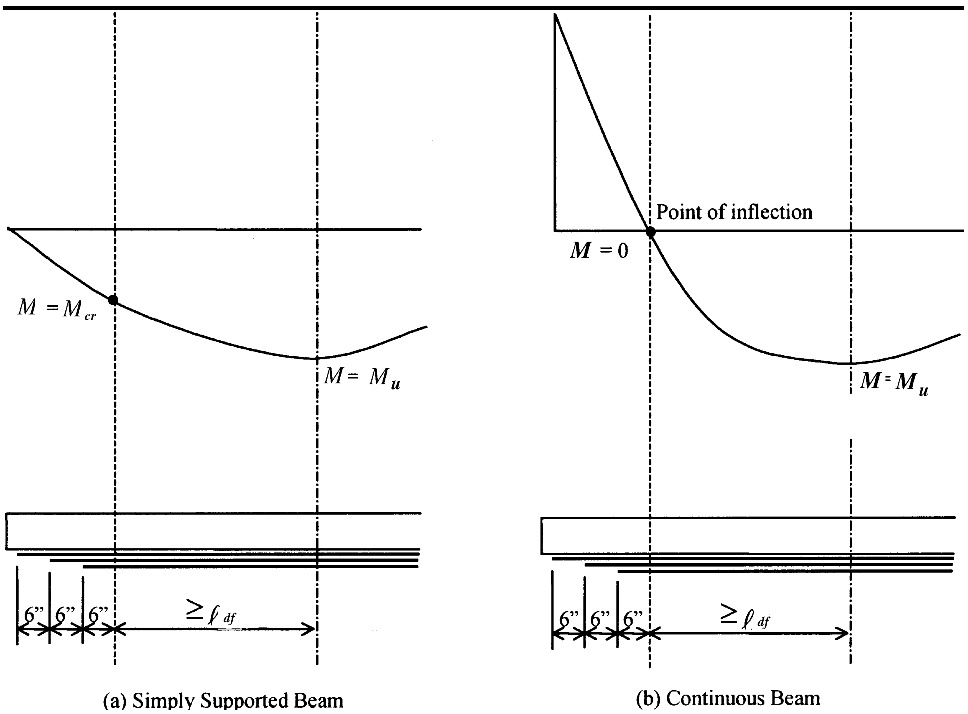

Fig. 12.3 — Graphical representation of the guidelines for allowable termination points of a three-ply FRP laminate.

with transverse reinforcement to prevent the concrete cover layer from splitting.

- For continuous beams, a single-ply FRP laminate should be terminated $d/2$ or 6 in. (150 mm) minimum beyond the inflection point (point of zero moment resulting from factored loads). For multiple-ply laminates, the termination points of the plies should be tapered. The outermost ply should be terminated no less than 6 in. (150 mm) beyond the inflection point. Each successive ply should be terminated no less than an additional 6 in. (150 mm) beyond the inflection point. For example, if a three-ply laminate is required, the ply directly in contact with the concrete substrate should be terminated at least 18 in. (460 mm) past the inflection point (Fig. 12.3). These guidelines apply for positive and negative moment regions.

12.2—Detailing of laps and splices

Splices of FRP laminates should be provided only as permitted on drawings or in specifications or as authorized by the engineer as recommended by the system manufacturer.

The fibers of FRP systems should be continuous and oriented in the direction of the largest tensile forces. Fiber continuity can be maintained with a lap splice. For FRP systems, a lap splice should be made by overlapping the fibers along their length. The required overlap, or lap-splice length, depends on the tensile strength and thickness of the FRP material system and on the bond strength between adjacent layers of FRP laminates. Sufficient overlap should be provided to promote the failure of the FRP laminate before debonding of the overlapped FRP laminates. The required overlap for an FRP system should be provided by the material manufacturer and substantiated through testing, independent of the manufacturer.

Jacket-type FRP systems used for column members should provide appropriate development area at splices, joints, and termination points to ensure failure through the FRP jacket thickness rather than failure of the spliced sections.

For unidirectional FRP laminates, lap splices are required only in the direction of the fibers. Lap splices are not required in the direction transverse to the fibers. FRP laminates consisting of multiple unidirectional sheets oriented in more than one direction or multidirectional fabrics require lap splices in more than one direction to maintain the continuity of the fibers and the overall strength of the FRP laminates.

CHAPTER 13—DRAWINGS, SPECIFICATIONS, AND SUBMITTALS

13.1—Engineering requirements

Although federal, state, and local codes for the design of externally bonded FRP systems do not exist, other applicable code requirements may influence the selection, design, and installation of the FRP system. For example, code requirements related to fire or potable water may influence the selection of the coatings used with the FRP system. All design work should be performed under the guidance of a licensed engineer familiar with the properties and applications of FRP-strengthening systems.

13.2—Drawings and specifications

The engineer should document calculations summarizing the assumptions and parameters used to design the FRP strengthening and should prepare design drawings and project specifications. The drawings and specifications should show, at a minimum, the following information specific to externally applied FRP systems:

- FRP system to be used;
- Location of the FRP system relative to the existing structure;
- Dimensions and orientation of each ply;
- Number of plies and the sequence of installation;

- Location of splices and lap length;
- General notes listing design loads and allowable strains in the FRP laminates;
- Material properties of the FRP laminates and concrete substrate;
- Concrete surface preparation requirements, including corner preparation and maximum irregularity limitations;
- Installation procedures, including surface temperature and moisture limitations, and application time limits between successive plies;
- Curing procedures of FRP systems;
- Protective coatings and sealants, if required;
- Shipping, storage, handling, and shelf-life guidelines;
- Quality control and inspection procedures, including acceptance criteria; and
- In-place load testing of installed FRP system, if necessary.

13.3—Submittals

Specifications should require the FRP system manufacturer; installation contractor; inspection agency, if required; and all those involved with the project to submit product information and evidence of their qualifications and experience to the engineer for review.

13.3.1 *FRP system manufacturer*—Submittals required of the FRP system manufacturer should include:

- Product data sheets indicating the physical, mechanical, and chemical characteristics of the FRP system and all its constituent materials;
- Tensile properties of the FRP system including the method of reporting properties (net fiber or gross laminate), test methods used, and the statistical basis used for determining the properties;
- Installation instructions, maintenance instructions, and general recommendations regarding each material to be used. Installation procedures should include surface preparation requirements;
- Manufacturer's Material Safety Data Sheets (MSDS) for all materials to be used;
- Quality-control procedure for tracking FRP materials and material certifications;
- Durability test data for the FRP system in the types of environments expected;
- Structural test reports pertinent to the proposed application; and
- Reference projects.

13.3.2 *FRP system installation contractor*—Submittals required of the FRP system installation contractor should include:

- Documentation from the FRP system manufacturer of having been trained to install the proposed FRP system;
- Project references, including installations similar to the proposed installation. For example, for an overhead application, the contractor should submit a list of previous installations involving the installation of the proposed FRP system in an overhead application;
- Evidence of competency in surface preparation techniques; and
- Quality-control procedures including the daily log or inspection forms used by the contractor.

13.3.3 *FRP system inspection agency*—If an independent inspection agency is used, submittals required of that agency should include:

- A list of inspectors to be used on the project and their qualifications;
- Sample inspection forms; and
- A list of previous projects inspected by the inspector.

PART 5—DESIGN EXAMPLES

CHAPTER 14—DESIGN EXAMPLES

14.1—Calculation of FRP system tensile strength

This example illustrates the derivation of material properties based on net-fiber area versus the properties based on gross-laminate area. As described in Section 3.3.1, both methods of determining material properties are valid. It is important, however, that any design calculations consistently use material properties based on only one of the two methods (for example, if the gross-laminate thickness is used in any calculation, the strength based on gross-laminate area should be used in the calculations as well).

A test panel is fabricated from two plies of a carbon fiber/epoxy unidirectional FRP system using the wet layup technique. Based on the known fiber content of this FRP system, the net-fiber area is 0.0065 in.^{2}/in. width/ply. After the system has cured, five 2 in. (5.08 cm) wide test coupons are cut from the panel. The test coupons are tested in tension to failure in accordance with ASTM D 3039. Tabulated in Table 14.1 are the results of the tension testing.

Table 14.1—FRP-system tension test results

	Specimen width		Measured coupon thickness		Measured rupture load	
Coupon ID	in.	mm	in.	mm	kips	kN
T-1	2	50.8	0.055	1.397	17.8	79.2
T-2	2	50.8	0.062	1.575	16.4	72.9
T-3	2	50.8	0.069	1.753	16.7	74.3
T-4	2	50.8	0.053	1.346	16.7	74.3
T-5	2	50.8	0.061	1.549	17.4	77.4
Average	2	50.8	0.060	1.524	17.0	75.6

Net-fiber area property calculations		Gross-laminate area property calculations	
Calculate Af using the known, net-fiber area ply thickness: $A_f = nt_fw_f$	$A_f = (2)\left(0.0065\frac{\text{in.}^2}{\text{in.}}\right)(2\text{ in.})$ $= 0.026\text{ in.}^2$	Calculate A_f using the average, measured laminate thickness: $A_f = t_fw_f$	$A_f = (0.060\text{ in.})(2\text{ in.}) = 0.120\text{ in.}^2$
	$A_f = (2)\left(0.1651\frac{\text{mm}^2}{\text{mm}}\right)(50.8\text{ mm})$ $= 16.774\text{ mm}^2$		$A_f = (1.524\text{ mm})(50.8\text{ mm})$ $= 77.419\text{ mm}^2$
Calculate the average FRP system tensile strength based on net-fiber area:	$\overline{f_{fu}} = \frac{17\text{ kips}}{0.026\text{ in.}^2} = 650\text{ ksi}$	Calculate the average FRP system tensile strength based on gross-laminate area:	$\overline{f_{fu}} = \frac{17\text{ kips}}{0.120\text{ in.}^2} = 140\text{ ksi}$
$\overline{f_{fu}} = \frac{\text{Average measured rupture load}}{A_f}$	$\overline{f_{fu}} = \frac{75.62\text{ kN}}{16.774\text{ mm}^2} = 4.508\text{ kN/mm}^2$	$\overline{f_{fu}} = \frac{\text{Average measured rupture load}}{A_f}$	$\overline{f_{fu}} = \frac{75.62\text{ kN}}{77.419\text{ mm}^2} = 0.997\text{ kN/mm}^2$
Calculate the average FRP system tensile strength per unit width based on net-fiber area: $\overline{p_{fu}} = \frac{\overline{f_{fu}}A_f}{w_f}$	$\overline{p_{fu}} = \frac{(650\text{ ksi})(0.026\text{ in.}^2)}{2\text{ in.}}$ $= 8.4\text{ kips/in.}$	Calculate the average FRP system tensile strength per unit width based on laminate area: $\overline{p_{fu}} = \frac{\overline{f_{fu}}A_f}{w_f}$	$\overline{p_{fu}} = \frac{(140\text{ ksi})(0.120\text{ in.}^2)}{2\text{ in.}}$ $= 8.4\text{ kips/in.}$
	$\overline{p_{fu}} = \frac{\left(4.508\frac{\text{kN}}{\text{mm}^2}\right)(16.774\text{ mm}^2)}{50.8\text{ mm}}$ $= 1.49\text{ kN/mm}$		$\overline{p_{fu}} = \frac{\left(0.977\frac{\text{kN}}{\text{mm}^2}\right)(77.419\text{ mm}^2)}{50.8\text{ mm}}$ $= 1.49\text{ kN/mm}$

14.2—Calculation of FRP system tensile strength

An engineer is considering two FRP systems for strengthening a reinforced concrete member and has obtained mechanical properties from the respective manufacturers. System A consists of dry, carbon-fiber unidirectional sheets and is installed with an epoxy resin using the wet layup technique. System B consists of precured carbon fiber/epoxy laminates that are bonded to the concrete surface with an epoxy resin. Excerpts from the data sheets provided by the FRP system manufacturers are given in Table 14.2. After reviewing the material data sheets sent by the FRP system manufacturers, the engineer compares the tensile strengths of the two systems.

Table 14.2—Material properties and description of two types of FRP system

System A (excerpts from data sheet)	System B (excerpts from data sheet)
System type: dry, unidirectional sheet Fiber type: high-strength carbon Polymer resin: epoxy *System A is installed using a wet layup procedure where the dry carbon-fiber sheets are impregnated and adhered with an epoxy resin on-site.*	System type: precured, unidirectional laminate Fiber type: high-strength carbon Polymer resin: epoxy *System B's precured laminates are bonded to the concrete substrate using System B's epoxy paste adhesive.*
Mechanical properties*†‡	Mechanical properties*†
$t_f = 0.013$ in. (0.330 mm)	$t_f = 0.050$ in. (1.270 mm)
$f_{fu}^* = 550$ ksi (3792 N/mm^2)	$f_{fu}^* = 380$ ksi (2620 N/mm^2)
$\varepsilon_{fu}^* = 1.7\%$	$\varepsilon_{fu}^* = 1.7\%$
$E_f = 33{,}000$ ksi (227,527 N/mm^2)	$E_f = 22{,}000$ ksi (151,724 N/mm^2)
Notes on System A: [*] Reported properties are based on a population of 20 or more coupons tested in accordance with ASTM D 3039. [†] Reported properties have been statistically adjusted by subtracting three standard deviations from the mean tensile stress and strain. [‡] Thickness is based on the net-fiber area for one ply of the FRP system. Resin is excluded. Actual installed thickness of cured FRP is 0.060 to 0.070 in. per ply.	Notes on System B: [*] Reported properties are based on a population of 20 or more coupons tested in accordance with ASTM D 3039. [†] Reported properties have been statistically adjusted by subtracting three standard deviations from the mean tensile stress and strain.

Because the data sheets for both systems are reporting statistically based properties, it is possible to directly compare the tensile strength and modulus of both systems. The calculations are shown below:

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 1A—Calculate the tensile strength per unit width of System A $p_{fu}^* = f_{fu}^* t_f$	p_{fu}^* = (550 ksi)(0.013 in.) = 7.15 kips/in.	p_{fu}^* = (3.79 kN/mm^2)(0.330 mm) = 1.25 kN/mm
Step 1B—Calculate the tensile strength per unit width of System B $p_{fu}^* = f_{fu}^* t_f$	p_{fu}^* = (380 ksi)(0.050 in.) = 19 kips/in.	p_{fu}^* = (2.62 kN/mm^2)(1.27 mm) = 3.33 kN/mm
Step 2A—Calculate the tensile modulus per unit width of System A $k_f = E_f t_f$	k_f = (33,000 ksi)(0.013 in.) = 429 kips/in.	k_f = (227.5 kN/mm^2)(0.330 mm) = 75.13 kN/mm
Step 2B—Calculate the tensile modulus per unit width of System B $k_f = E_f t_f$	k_f = (22,000 ksi)(0.050 in.) = 1100 kips/in.	k_f = (151.7 kN/mm^2)(1.27 mm) = 192.63 kN/mm
Step 3—Compare the two systems Compare the tensile strengths: $\frac{p_{fu}^* \text{ (System A)}}{p_{fu}^* \text{ (System B)}}$	$\frac{p_{fu}^*\text{(System B)}}{p_{fu}^*\text{(System A)}} = \frac{19 \text{ kips/in.}}{7.5 \text{ kips/in.}} = 2.66$ ∴ three plies of System A are required for each ply of System B for an equivalent tensile strength	$\frac{p_{fu}^*\text{(System B)}}{p_{fu}^*\text{(System A)}} = \frac{3.33 \text{ kN/mm}}{75.13 \text{ kN/mm}} = 2.66$ ∴ three plies of System A are required for each ply of System B for an equivalent tensile strength
Compare the stiffnesses: $\frac{k_f \text{(System A)}}{k_f \text{(System B)}}$	$\frac{k_f\text{(System B)}}{k_f\text{(System A)}} = \frac{1100 \text{ kips/in.}}{429 \text{ kips/in.}} = 2.56$ ∴ three plies of System A are required for each ply of System B for an equivalent stiffness	$\frac{k_f\text{(System A)}}{k_f\text{(System B)}} = \frac{192.63 \text{ kN/mm}}{75.13 \text{ kN/mm}} = 2.56$ ∴ three plies of System A are required for each ply of System B for an equivalent stiffness

Because all the design procedures outlined in this document limit the strain in the FRP material, the full ultimate strength of the material is not utilized and should not be the basis of comparison between two material systems. When considering various FRP material systems for a particular application, the FRP systems should be compared based on equivalent stiffness only. In addition, each FRP system under consideration should have the ability to develop the strain level associated with the effective strain level required by the application without rupturing, $\varepsilon_{fu} > \varepsilon_{fe}$.

In many instances, it may be possible to vary the width of the FRP strip as opposed to the number of plies (use larger widths for systems with lower thicknesses and visa versa). In such instances, equivalent stiffness calculations typically will not yield equivalent contributions to the strength of a member. In general, thinner (lower nt_f) and wider (higher w_f) FRP systems will provide a higher level of strength to a member due to lower bond stresses. The exact equivalency, however, can only be found by performing complete calculations (according to procedures described in Chapters 9, 10, and 11 of this guide) for each system.

14.3—Flexural strengthening of an interior beam

A simply supported concrete beam reinforced with three No. 9 bars (Fig. 14.1) is located in a unoccupied warehouse and is subjected to a 50% increase in its live-load carrying requirements. An analysis of the existing beam indicates that the beam still has sufficient shear strength to resist the new required shear strength and meets the deflection and crack control serviceability requirements. Its flexural strength, however, is inadequate to carry the increased live load.

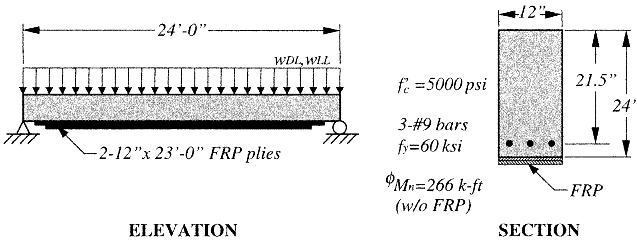

Fig. 14.1—Schematic of the idealized simply supported beam with FRP external reinforcement.

Length of the beam l	24 ft	7.31 m
Width of the beam w	12 in.	30.48 cm
d	21.5 in.	54.61 cm
h	24 in.	60.96 cm
f_c'	5000 psi	34 N/mm^2
f_y'	60 ksi	414 N/mm^2
ϕM_n without FRP	266 k-ft	355.3 kN × m
Bars	No. 9	ϕ28

Summarized in Table 14.3 are the existing and new loadings and associated midspan moments for the beam.

Table 14.3—Loadings and corresponding moments

Loading/moment	Existing loads		Anticipated loads	
Dead loads w_{DL}	1.00 k/ft	14 N/mm	1.00 k/ft	14 N/mm
Live load w_{LL}	1.20 k/ft	17 N/mm	1.80 k/ft	26 N/mm
Unfactored loads ($w_{DL} + w_{LL}$)	2.20 k/ft	32.1 N/mm	2.80 k/ft	40.9 N/mm
Unstrengthened load limit ($1.2w_{DL} + 0.85w_{LL}$)	N/A	N/A	2.73 k/ft	39.8 N/mm
Factored loads ($1.4w_{DL} + 1.7w_{LL}$)	3.44 k/ft	50.2 N/mm	4.46 k/ft	65.1 N/mm
Dead-load moment M_{DL}	72 k-ft	96.2 kN-m	72 k-ft	96.2 kN-m
Live-load moment M_{LL}	86 k-ft	114.9 kN-m	130 k-ft	173.6 kN-m
Service-load moment M_s	158 k-ft	211.1 kN-m	202 k-ft	269.8 kN-m
Unstrengthened moment limit ($1.2M_{DL} + 0.85M_{LL}$)	N/A	N/A	197 k-ft	263.2 kN-m
Factored moment M_u	248 k-ft	331.3 kN-m	321 k-ft	428.8 kN-m

It is proposed to strengthen the existing reinforced concrete beam with the FRP system described in Table 14.4. Specifically, two 12 in. (25.4 mm) wide x 23.0 ft (7 m) long plies are to be bonded to the soffit of the beam using the wet layup technique.

Table 14.4—Manufacturer's reported FRP-system properties

Thickness per ply t_f	0.040 in.	1.016 mm
Ultimate tensile strength f_{fu}^*	90 ksi	0.62 kN/mm^2
Rupture strain ε_{fu}^*	0.017 in./in.	0.017 mm/mm
Modulus of elasticity of FRP laminates E_f	5360 ksi	37 kN/mm^2

By inspection, the level of strengthening is reasonable in that it does meet the strengthening limit criteria put forth in Eq. (8-1). That is, the existing moment strength, $(\phi M_n)_{w/o\ FRP}$ = 266 k-ft (355 kN-m), is greater than the unstrengthened moment limit, $(1.2M_{DL} + 0.85M_{LL})_{new}$ = 197 k-ft (263 kN-m). The design calculations used to verify this configuration follow.

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 1—Calculate the FRP-system design material properties The beam is located in an interior space and a CFRP material will be used. Therefore, per Table 8.1, an environmental-reduction factor of 0.95 is suggested. $f_{fu} = C_E f_{fu}^*$ $\varepsilon_{fu} = C_E \varepsilon_{fu}^*$	f_{fu} = (0.95)(90 ksi) = 85 ksi ε_{fu} = (0.95)(0.017 in./in.) = 0.0162 in./in.	f_{fu} = (0.95)(620.53 N/mm^2) = 589.5 N/mm^2 ε_{fu} = (0.95)(0.017 mm/mm) = 0.0162 mm/mm
Step 2—Preliminary calculations Properties of the concrete: β_1 from ACI 318-99, Section 10.2.7.3 $E_c = 57,000\sqrt{f'_c}$	$\beta_1 = 1.05 - 0.05\dfrac{f'_c}{1000} = 0.80$ $E_c = 57,000\sqrt{5000\text{ psi}} = 4,030,000\text{ psi}$	$\beta_1 = 1.09 - 0.08f'_c\ (\text{N/mm}^2) = 0.81$ $E_c = 57,000\sqrt{34.47\text{ N/mm}^2} = 334,672\text{ N/mm}^2$
Properties of the existing reinforcing steel:	$A_s = 3(1.00\text{ in.}^2) = 3.00\text{ in.}^2$	$A_s = 3(615.7\text{ mm}^2) = 1935.48\text{ mm}^2$
$\rho_s \equiv \dfrac{A_s}{bd}$	$\rho_s = \dfrac{3.00\text{ in.}^2}{(12\text{ in.})(21.5\text{ in.})} = 0.00116$	$\rho_s = \dfrac{1935.48\text{ mm}^2}{(304.8\text{ mm})(546.1\text{ mm})} = 0.00116$
Properties of the externally bonded FRP reinforcement: $A_f = nt_fw_f$	A_f = (2 plies)(0.040 in./ply)(12 in.) = 0.96 in.^{2}	A_f = (2 plies)(1.016 mm/ply)(304.8 mm) = 619.35 mm^2
$\rho_f = \dfrac{A_f}{bd}$	$\rho_s = \dfrac{0.96\text{ in.}^2}{(12\text{ in.})(21.5\text{ in.})} = 0.00372$	$\rho_s = \dfrac{619.35\text{ mm}^2}{(304.8\text{ mm})(546.1\text{ mm})} = 0.00372$

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 3—Determine the existing state of strain on the soffit The existing state of strain is calculated assuming the beam is cracked and the only loads acting on the beam at the time of the FRP installation are dead loads. A cracked section analysis of the existing beam gives k = 0.334 and I_{cr} = 5905 in.^{4} = 2451 × 10^6 mm^4 $\varepsilon_{bi} = \frac{M_{DL}(h-kd)}{I_{cr}E_c}$	$\varepsilon_{bi} = \frac{(864\text{ k}\cdot\text{in.})[24\text{ in.} - (0.334)(21.5\text{ in.})]}{(5905\text{ in.}^4)(4030\text{ ksi})}$ $\varepsilon_{bi} = 0.00061$	$\varepsilon_{bi} =$ $\frac{(97{,}632\text{ kN}\cdot\text{mm})[609.6\text{ mm} - (0.334)(546.1\text{ mm})]}{(2451\cdot 10^6\text{ mm}^4)(28\text{ kN/mm}^2)}$ $\varepsilon_{bi} = 0.00061$
Step 4—Determine the bond-dependent coefficient of the FRP system The dimensionless bond-dependent coefficient for flexure κ_m is calculated using Eq. (9-2) Compare nE_ft_f to 1,000,000 Therefore, $\kappa_m = \frac{1}{60\varepsilon_{fu}}\left(1 - \frac{nE_ft_f}{2{,}000{,}000}\right) \le 0.90$	(2)(5,360,000 psi)(0.040 in.) = 428,8000 < 1,000,000 $\kappa_m =$ $\frac{1}{60(0.0162)}\left[1 - \frac{(2)(5{,}360{,}000\text{ psi})(0.040\text{ in.}))}{2{,}000{,}000}\right]$ $\kappa_m = 0.82 < 0.9$	(2)(37 kN/mm^2)(1.016 mm) = 75,184 < 175,336 $\kappa_m = \frac{1}{60(0.0162)}\left[1 - \frac{(2)(37\text{ kN/mm}^2)(1.016\text{ mm})}{175{,}336}\right]$ $\kappa_m = 0.588 < 0.6$
Step 5—Estimate c, the depth to the neutral axis A reasonable initial estimate of c is 0.20d. The value of the c is adjusted after checking equilibrium. $c = 0.20d$	c = (0.20)(21.5 in.) = 4.30 in.	c = (0.20)(546.1 mm) = 109.2 mm
Step 6—Determine the effective level of strain in the FRP reinforcement The effectiveness strain level in the FRP may be found from Eq. (9-3). $\varepsilon_{fe} = 0.003\left(\frac{h-c}{c}\right) - \varepsilon_{bi} \le \kappa_m\varepsilon_{fu}$ Note that for the neutral axis depth selected, concrete crushing would be the failure mode because the first expression in this equation controls. If the second (limiting) expression governed, then FRP failure would be in the failure mode.	$\varepsilon_{fe} = 0.003\left(\frac{24-4.3}{4.3}\right) - 0.00061 \le 0.82(0.0162)$ $\varepsilon_{fe} = 0.0131 \le 0.0133$	$\varepsilon_{fe} = 0.003\left(\frac{617.2\text{ mm} - 109.2\text{ mm}}{109.2\text{ mm}}\right) - 0.00061$ $\le 0.82(0.0162)$ $\varepsilon_{fe} = 0.0131 \le 0.0133$
Step 7—Calculate the strain in the existing reinforcing steel The strain in the reinforcing steel can be calculated using similar triangles according to Eq. (9-8). $\varepsilon_s = (\varepsilon_{fe} + \varepsilon_{bi})\left(\frac{d-c}{h-c}\right)$	$\varepsilon_s = (0.0131 + 0.00061)\left(\frac{21.5-4.30}{24-4.30}\right) = 0.012$	$\varepsilon_s = (0.0131 + 0.00061)\left(\frac{546.1-109.2}{609.6-109.2}\right) = 0.012$
Step 8—Calculate the stress level in the reinforcing steel and FRP The stresses are calculated using Eq. (9-9) and (9-4). $f_s = E_s\varepsilon_s \le f_y$ $f_{fe} = E_f\varepsilon_{fe}$	f_s = (29,000 ksi)(0.012) ≤ 60 ksi f_s = 348 ksi ≤ 60 ksi f_{fe} = (5360 ksi)(0.0131) = 70.2 ksi	f_s = (200 kN/mm^2)(0.012) ≤ 0.14 kN/mm^2 f_s = 2.4 kN/mm^2 ≤ 0.14 kN/mm^2 f_{fe} = (37 kN/mm^2)(0.0131) = 0.5 kN/mm^2
Step 9—Calculate the internal force resultants and check equilibrium Force equilibrium is verified by checking the initial estimate of c with Eq. (9-10). (Because concrete crushing controls failure, γ can be taken as 0.85.) $c = \frac{A_sf_s + A_ff_{fe}}{\gamma f_c'\beta_1 b}$	$c = \frac{(3.00\text{ in.}^2)(60\text{ ksi}) + (0.96\text{ in.}^2)(70.2\text{ ksi})}{(0.85)(5\text{ ksi})(0.80)(12\text{ in.})}$ c = 6.06 in. ≠ 4.030 in. n.g. ∴ Revise estimate of c and repeat Steps 6 through 9 until equilibrium is achieved.	$c =$ $\frac{(1935.48\text{ mm}^2)(413.7\text{ N/mm}^2) + (619\text{ mm}^2)(484\text{ N/mm}^2)}{(0.85)(34.47\text{ N/mm}^2)(0.81)(305\text{ mm})}$ c = 152 mm ≠ 109 in. n.g. ∴ Revise estimate of c and repeat Steps 6 through 9 until equilibrium is achieved.

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 10—Adjust *c* until force equilibrium is satisfied Steps 6 through 9 were repeated several times with different values of *c* until equilibrium was achieved. The results of the final iteration are $c = 5.58$ in.; $\varepsilon_s = 0.0086$; $f_s = f_y = 60$ ksi; $\varepsilon_{fe} = 0.0093$; and $f_{fe} = 49.8$ ksi	$c = \dfrac{(3.00\text{ in.}^2)(60\text{ ksi}) + (0.96\text{ in.}^2)(49.8\text{ ksi})}{(0.85)(5\text{ ksi})(0.80)(12\text{ in.})}$ $c = 5.58$ in. = 5.58 in. ✓ O.K. ∴ the value of *c* selected for the final iteration is correct.	$c = \dfrac{(1935.48\text{ mm}^2)(0.41\text{ kN/m}^2) + (619\text{ mm}^2)(0.34\text{ kN/mm}^2)}{(0.85)(0.03\text{ kN/mm}^2)(0.81)(305\text{ mm})}$ $c = \dfrac{(1935\text{ mm}^2)(413.7\text{ N/mm}^2) + (619\text{ mm}^2)(343\text{ N/mm}^2)}{(0.85)(34.47\text{ N/mm}^2)(0.81)(305\text{ mm})}$ $c = 142$ mm = 142 mm ✓ O.K. ∴ the value of *c* selected for the final iteration is correct.
Step 11—Calculate design flexural strength of the section The design flexural strength is calculated using Eq. (9-11). An additional reduction factor, $\psi_f = 0.85$, is applied to the contribution of the FRP system. Because $\varepsilon_s = 0.0086 > 0.005$, a strength-reduction factor of $\phi = 0.90$ is appropriate per Eq. (9-5). $\phi M_n = \phi\left[A_s f_s\left(d - \dfrac{\beta_1 c}{2}\right) + \psi A_f f_{fe}\left(h - \dfrac{\beta_1 c}{2}\right)\right]$	$\phi M_n = 0.90\Big[(3.00\text{ in.}^2(60\text{ ksi})$ $\left(21.5\text{ in.} - \dfrac{(0.80)(5.58\text{ in.})}{2}\right) + (0.85)(0.96\text{ in.}^2)$ $(49.8\text{ ksi})\left(24\text{ in.} - \dfrac{(0.80)(5.58\text{ in.})}{2}\right)\Big]$ $\phi M_n = 3920\text{ k}\cdot\text{in.} = 326\text{ k}\cdot\text{ft} \geq M_u = 321\text{ k}\cdot\text{ft}$ ∴ the strengthened section is capable of sustaining the new required moment strength.	$\phi M_n = 0.90\Big[(1935.48\text{ mm}^2)(414\text{ N/mm}^2)$ $\left(546\text{ mm} - \dfrac{(0.81)(142\text{ mm})}{2}\right) + (0.85)(546\text{ mm}^2)$ $(343\text{ N/mm}^2)\left(607\text{ mm} - \dfrac{(0.81)(142\text{ mm})}{2}\right)\Big]$ $\phi M_n = 435{,}329\text{ N}\cdot\text{mm} = 435.3\text{ N}\cdot\text{mm} \geq M_u = 428.7\text{ N}\cdot\text{m}$ ∴ the strengthened section is capable of sustaining the new required moment strength.
Step 12—Check service stresses in the reinforcing steel and the FRP Calculate the elastic depth to the cracked neutral axis by adding the first moment of the areas of the transformed section. This can be simplified for a rectangular beam without compression reinforcement as follows: $k = \sqrt{\left(\rho_s\dfrac{E_s}{E_c} + \rho_f\dfrac{E_f}{E_c}\right)^2 + 2\left(\rho_s\dfrac{E_s}{E_c} + \rho_f\dfrac{E_f}{E_c}\left(\dfrac{h}{d}\right)\right)} - \left(\rho_s\dfrac{E_s}{E_c} + \rho_f\dfrac{E_f}{E_c}\right)$ Calculate the stress level in the reinforcing steel using Eq. (9-12) and verify that it is less than recommended limit per Eq. (9-6). $f_{s,s} = \dfrac{\left[M_s + \varepsilon_{bi}A_f E_f\left(h - \frac{kd}{3}\right)\right](d - kd)E_s}{A_s E_s\left(d - \frac{kd}{3}\right)(d - kd) + A_f E_f\left(h - \frac{kd}{3}\right)(h - kd)}$ $f_{s,s} \leq 0.80 f_y$	*See EQUATION NOTE I (U.S.) below. $k = 0.343$ $kd = (0.343)(21.5\text{ in.}) = 7.37$ in. †See EQUATION NOTE II (U.S.) below. $f_{s,s} = 40.4\text{ ksi} \leq (0.80)(60\text{ ksi}) = 48\text{ ksi}$ ∴ the stress level in the reinforcing steel is within the recommended limit.	**See EQUATION NOTE I (SI) below. $k = 0.343$ $kd = (0.343)(546.1\text{ mm}) = 187.3$ mm ††See EQUATION NOTE II (SI) below. $f_{s,s} = 280\text{ N/mm}^2 \leq (0.80)(410\text{ N/mm}^2) = 330\text{ N/mm}^2$ ∴ the stress level in the reinforcing steel is within the recommended limit.

*EQUATION NOTE I (U.S.):

$$k = \sqrt{\left(0.0116\left(\frac{29{,}000}{4030}\right) + 0.00372\left(\frac{5360}{4030}\right)\right)^2 + 2\left(0.0116\left(\frac{29{,}000}{4030}\right) + 0.00372\left(\frac{5360}{4030}\right)\left(\frac{24\text{ in.}}{21.5\text{ in.}}\right)\right)} - \left(0.0116\left(\frac{29{,}000}{4030}\right) + 0.00372\left(\frac{5360}{4030}\right)\right)$$

EQUATION NOTE I (SI):

$$k = \sqrt{\left(0.0116\left(\frac{200}{28}\right) + 0.00372\left(\frac{37}{28}\right)\right)^2 + 2\left(0.0116\left(\frac{200}{28}\right) + 0.00372\left(\frac{37}{28}\right)\left(\frac{609.6\text{ mm}}{546.1\text{ mm}}\right)\right)} - \left(0.0116\left(\frac{200}{28}\right) + 0.00372\left(\frac{37}{28}\right)\right)$$

†EQUATION NOTE II (U.S.):

$$f_{s,s} = \frac{\left[2424\text{ k}\cdot\text{in.} + (0.00061)(0.96\text{ in.}^2)(5360\text{ ksi})\left(24\text{ in.} - \frac{7.37\text{ in.}}{3}\right)\right](21.5\text{ in.} - 7.37\text{ in.})(29{,}000\text{ ksi})}{(3.00\text{ in.}^2)(29{,}000\text{ ksi})\left(21.5\text{ in.} - \frac{7.37\text{ in.}}{3}\right)(21.5\text{ in.} - 7.37\text{ in.}) + (0.96\text{ in.}^2)(5360\text{ ksi})\left(24\text{ in.} - \frac{7.37\text{ in.}}{3}\right)(24\text{ in.} - 7.37\text{ in.})}$$

††EQUATION NOTE II (SI):

$$f_{s,s} = \frac{\left[273{,}912\text{ kN}\cdot\text{mm} + (0.00061)(619.35\text{ mm}^2)(37\text{ kN/mm}^2)\left(609.6\text{ mm} - \frac{187.2\text{ mm}}{3}\right)\right](546.1\text{ mm} - 187.2\text{ mm})(200\text{ kN/mm}^2)}{(1847\text{ mm}^2)(200\text{ kN/mm}^2)\left(546.1\text{ mm} - \frac{187.2\text{ mm}}{3}\right)(546.1\text{ mm} - 187.2\text{ mm}) + (619.35\text{ mm}^2)(37\text{ kN/mm}^2)\left(609.6\text{ mm} - \frac{187.2\text{ mm}}{3}\right)(609.6\text{ mm} - 187.2\text{ mm})}$$

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 12 (cont.)— Calculate the stress level in the FRP using Eq. (9-13) and verify that it is less than creep-rupture stress limit given in Table 9.1. Assume that the full service load is sustained.		
$f_{f,s} = f_{s,s}\left(\frac{E_f}{E_s}\right)\left(\frac{h-kd}{d-kd}\right) - \varepsilon_{bi}E_f$	$f_{f,s} = 40.4\text{ ksi}\left(\frac{5360\text{ ksi}}{29{,}000\text{ ksi}}\right)\left(\frac{24\text{ in.} - 7.37\text{ in.}}{21.5\text{ in.} - 7.37\text{ in.}}\right)$	$f_{f,s} = 0.278\text{ kN/mm}^2\left(\frac{37\text{ kN/mm}^2}{200\text{ kN/mm}^2}\right)\left(\frac{609.6\text{ mm} - 187.2\text{ mm}}{546.1\text{ mm} - 187.2\text{ mm}}\right)$
For a carbon FRP system, the sustained plus cyclic stress limit is obtained from Table 9.1:	$-(0.00061)(5360\text{ ksi})$	$\left(\frac{609.6\text{ mm} - 187.2\text{ mm}}{546.1\text{ mm} - 187.2\text{ mm}}\right) - (0.00061)(371\text{ kN/mm}^2)$
Sustained plus cyclic stress limit = $0.55f_{fu}$	$f_{f,s} = 5.60\text{ ksi} \leq (0.55)(85\text{ ksi}) = 50\text{ ksi}$	$f_{f,s} = 38.6\text{ N/mm}^2 \leq (0.55)(586\text{ N/mm}^2) = 322.3\text{ N/mm}^2$
	∴ the stress level in the FRP is within the recommended sustained plus cyclic stress limit.	∴ the stress level in the FRP is within the recommended sustained plus cyclic stress limit.

In detailing the FRP reinforcement, the FRP should be terminated a minimum of *d* past the point on the moment diagram that represents cracking. The factored shear force at the termination should also be checked against 2/3 of the concrete shear strength. If the shear force is greater than 2/3 of the concrete shear strength, FRP U-wraps are recommended to reinforce against cover delamination.

14.4—Shear strengthening of an interior T-beam

A reinforced concrete T-beam ($f_c' = 3000$ psi = 20.7 N/mm^2), located inside of an office building, is subjected to an increase in its live-load carrying requirements. An analysis of the existing beam indicates that the beam is still satisfactory for flexural strength; however, its shear strength is inadequate to carry the increased live load. Based on the analysis, the nominal shear strength provided by the concrete is V_c = 36.4 kips = 162 kN and the nominal shear strength provided by steel shear reinforcement is V_s = 19.6 kips = 87.2 kN. Thus, the design shear strength of the existing beam is $\phi V_{n,existing}$ = 0.85(36.4 kips + 19.6 kips) = 47.6 kips = 211.7 kN. The factored required shear strength, including the increased live load, at a distance *d* away from the support is V_u = 60 kips = 266.7 kN. Figure 14.2 shows the shear diagram with the locations where shear strengthening is required along the length of the beam.

Supplemental FRP shear reinforcement is designed as shown in Fig. 14.3 and summarized in Table 14.5. Each FRP strip consists of one ply ($n = 1$) of a flexible carbon sheet installed by wet layup. The FRP system manufacturer's reported material properties are shown in Table 14.6.

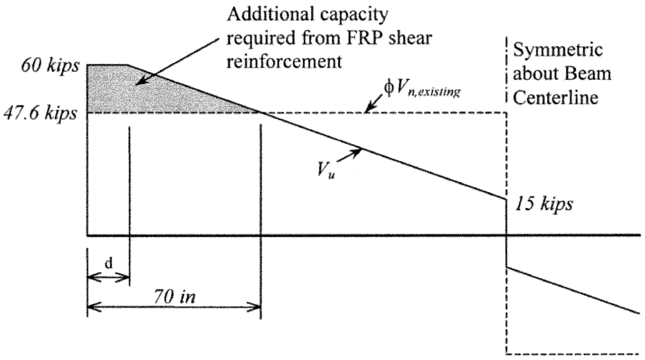

Fig. 14.2—Shear diagram showing demand versus existing strength. The FRP reinforcement should correct the deficiency shown shaded.

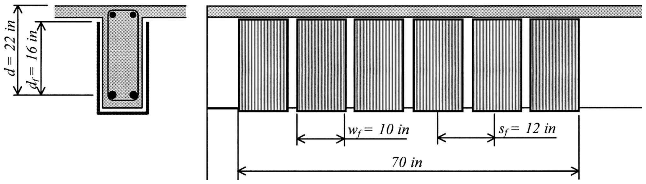

Fig. 14.3—Configuration of the supplemental FRP shear reinforcement.

Table 14.5—Configuration of the supplemental FRP shear reinforcement

d	22 in.	55.88 cm
d_f	16 in.	40.64 cm
Width of each sheet w_f	10 in.	25.4 cm
Span between each sheet s_f	12 in.	30.48 cm
FRP strip length	70 in.	177.8 cm

Table 14.6—Manufacturer's reported FRP system properties

Thickness per ply, t_f	0.0065 in.	0.1651 mm
Ultimate tensile strength f_{fu}^*	550,000 psi	3792 N/mm^2
Rupture strain ε_{fu}^*	0.017 in./in.	0.017 mm/mm
Modulus of elasticity E_f	33,000,000 psi	227,527 N/mm^2

The design calculations used to arrive at this configuration follow.

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 1—Compute the design material properties The beam is located in an enclosed and conditioned space and a CFRP material will be used. Therefore, per Table 8.1, an environmental-reduction factor of 0.95 is suggested.		
$f_{fu} = C_E f_{fu}^*$	$f_{fu} = (0.95)(550 \text{ ksi}) = 522.5 \text{ ksi}$	$f_{fu} = (0.95)(3.79 \text{ kN/mm}^2) = 3.60 \text{ kN/mm}^2$
$\varepsilon_{fu} = C_E \varepsilon_{fu}^*$	$\varepsilon_{fu} = (0.95)(0.017) = 0.016$	$\varepsilon_{fu} = (0.95)(0.017) = 0.016$
Step 2—Calculate the effective strain level in the FRP shear reinforcement The effective strain in FRP U-wraps should be determined using the bond-reduction coefficient κ_v. This coefficient can be computed using Eq. (10-7) through (10-10).		
$L_e = \dfrac{2500}{(n t_f E_f)^{0.58}}$	$L_e = \dfrac{2500}{[(1)(0.0065 \text{ in.})(33 \times 10^6 \text{ psi})]^{0.58}} = 2.0 \text{ in.}$	$L_e = \dfrac{416}{[(1)(0.1651 \text{ mm })(227.53 \text{ kN/mm}^2)]^{0.58}} = 50.8\text{mm}$
$k_1 = \left(\dfrac{f_c'}{4000}\right)^{2/3}$	$k_1 = \left(\dfrac{3000 \text{ psi}}{4000}\right)^{2/3} = 0.82$	$k_1 = \left(\dfrac{20.68 \text{ kN/mm}^2}{254}\right)^{2/3} = 0.82$
$k_2 = \left(\dfrac{d_f - L_e}{d_f}\right)$	$k_2 = \left(\dfrac{16 \text{ in.} - 2.0 \text{ in.}}{16 \text{ in.}}\right) = 0.875$	$k_2 = \left(\dfrac{406.4 \text{ mm} - 50.8 \text{ mm}}{406.4 \text{ mm}}\right) = 0.875$
$\kappa_v = \dfrac{k_1 k_2 L_e}{468 \varepsilon_{fu}} \leq 0.75$	$\kappa_v = \dfrac{(0.82)(0.875)(2 \text{ in.})}{468(0.016)} = 0.192 \leq 0.75$	$\kappa_v = \dfrac{(0.82)(0.875)(50.8 \text{ mm})}{468(0.016)} = 0.192 \leq 0.75$
The effective strain can then be computed using Eq. (10-6b) as follows: $\varepsilon_{fe} = \kappa_v \varepsilon_{fu} \leq 0.004$	$\varepsilon_{fe} = 0.192(0.016) = 0.0031 \leq 0.004$	$\varepsilon_{fe} = 0.192(0.016) = 0.0031 \leq 0.004$
Step 3—Calculate the contribution of the FRP reinforcement to the shear strength The area of FRP shear reinforcement can be computed as follows:		
$A_{fv} = 2 n t_f w_f$	$A_{fv} = 2(1)(0.0065 \text{ in.})(10 \text{ in.}) = 0.13 \text{ in.}^2$	$A_{fv} = 2(1)(0.1651 \text{ mm})(254 \text{ mm}) = 83.87 \text{ mm}^2$
The effective stress in the FRP can be computed from Hooke's law.		
$f_{fe} = \varepsilon_{fe} E_f$	$f_{fe} = (0.0031)(33{,}000 \text{ ksi}) = 102 \text{ ksi}$	$f_{fe} = (0.0031)(227.52 \text{ kN/mm}^2) = 0.703 \text{ kN/mm}^2$
The shear contribution of the FRP can be then calculated from Eq. (10-3).		
$V_f = \dfrac{A_{fv} f_{fe} (\sin\alpha + \cos\alpha) d_f}{s_f}$	$V_f = \dfrac{(0.13 \text{ in.}^2)(102 \text{ ksi})(1)(16 \text{ in.})}{(12 \text{ in.})}$ $V_f = 17.7 \text{ kips}$	$V_f = \dfrac{(83.87 \text{ mm}^2)(0.703 \text{ kN/mm}^2)(1)(406.4 \text{ mm})}{(304.8 \text{ mm})}$ $V_f = 78.73 \text{ kN}$
Step 4—Calculate the shear strength of the section The design shear strength can be computed from Eq. (10-2) with $\psi_f = 0.85$ for U-wraps.		
$\phi V_n = \phi(V_c + V_s + \psi_f V_f)$	$\phi V_n = 0.85[36.4 + 19.6 + (0.85)(17.7)]$ $\phi V_n = 60.4 \text{ kips} > V_n = 60 \text{ kips}$	$\phi V_n = 0.85[162 + 87.2 + (0.85)(78.73)]$ $\phi V_n = 268.7 \text{ kN} > V_n = 267 \text{ kN}$
	∴ the strengthened section is capable of sustaining the required shear strength.	∴ the strengthened section is capable of sustaining the required shear strength.

14.5—Shear strengthening of an exterior column

A 24 x 24 in. square column requires an additional 60 kips of shear strength (ΔV_u = 60 kips). The column is located in an unenclosed parking garage and experiences wide variation in temperature and climate. A method of strengthening the column using FRP is sought.

An E-glass/epoxy FRP complete wrap is selected to retrofit the column. The properties of the FRP system, as reported by the manufacturer, are shown in Table 14.7. The design calculations to arrive at the number of complete wraps required follow.

Procedure	Calculation in inch-pound units	Calculation in SI metric units
Step 1—Compute the design material properties The column is located in an exterior environment and a GFRP material will be used. Therefore, per Table 8.1, an environmental-reduction factor of 0.65 is suggested. $f_{fu} = C_E f_{fu}^*$ $\varepsilon_{fu} = C_E \varepsilon_{fu}^*$	$f_{fu} = (0.65)(80\text{ ksi}) = 52\text{ ksi}$ $\varepsilon_{fu} = (0.65)(0.020) = 0.013$	$f_{fu} = (0.65)(551.6\text{ N/mm}^2) = 358.5\text{ N/mm}^2$ $\varepsilon_{fu} = (0.65)(0.020) = 0.013$
Step 2—Calculate the effective strain level in the FRP shear reinforcement The effective strain in a complete FRP wrap can be determined from Eq. (10-6a): $\varepsilon_{fe} = 0.004 \le 0.75\varepsilon_{fu}$	$\varepsilon_{fe} = 0.004 \le 0.75(0.013) = 0.010$ $\therefore$ use an effective strain of $\varepsilon_{fe} = 0.004$.	$\varepsilon_{fe} = 0.004 \le 0.75(0.013) = 0.010$ $\therefore$ use an effective strain of $\varepsilon_{fe} = 0.004$.
Step 3—Determine the area of FRP reinforcement required The required shear contribution of the FRP reinforcement can be computed based on the increase in strength needed, the strength-reduction factor for shear, and a partial-reduction factor of 0.95 for completely wrapped sections in shear. $V_{f,\,reqd} = \dfrac{\Delta V_u}{\phi(\psi)}$ The required area of FRP can be determined by reorganizing Eq. (10-3). The required area is left in terms of the spacing. $A_{fv,\,reqd} = \dfrac{V_{f,\,reqd}s_f}{\varepsilon_{fe}E_{fe}(\sin\alpha + \cos\alpha)d_f}$	$V_{f,\,reqd} = \dfrac{60\text{ kips}}{0.85(0.95)} = 74.3\text{ kips}$ $A_{fv,\,reqd} = \dfrac{(74.3\text{ kips})s_f}{(0.004)(4000\text{ ksi})(1)(24\text{ in.})} = 0.194s_f$	$V_{f,\,reqd} = \dfrac{266.9\text{ kN}}{0.85(0.95)} = 330.5\text{ kN}$ $A_{fv,\,reqd} = \dfrac{(330.5\text{ kN})s_f}{(0.004)(27.6\text{ kN/mm}^2)(1)(609.6\text{ mm})}$ $= 4.91s_f$
Step 4—Determine the number of plies and strip width and spacing The number of plies can be determined in terms of the strip width and spacing as follows: $n = \dfrac{A_{f,\,reqd}}{2t_f w_f}$	$n = \dfrac{0.194s_f}{2(0.051\text{ in.})w_f} = 1.90\dfrac{s_f}{w_f}$ $\therefore$ use two plies ($n = 2$) continuously along the height of the column ($s_f = w_f$).	$n = \dfrac{4.91s_f}{2(1.29\text{ mm})w_f} = 1.90\dfrac{s_f}{w_f}$ $\therefore$ use two plies ($n = 2$) continuously along the height of the column ($s_f = w_f$).

Table 14.7—Manufacturer's reported FRP system properties*

Thickness per ply t_f	0.051 in.	1.29 mm
Guaranteed ultimate tensile strength f_{fu}^*	80,000 psi	551.6 N/mm^2
Guaranteed rupture strain ε_{fu}^*	0.020 in./in.	0.020 mm/mm
Modulus of elasticity E_f	4,000,000 psi	27,579 N/mm^2

*The reported properties are laminate properties.

CHAPTER 15—REFERENCES

15.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute (ACI)

201.1R	Guide for Making a Condition Survey of Concrete in Service
216R	Guide for Determining Fire Endurance of Concrete Elements
224R	Control of Cracking in Concrete Structures
224.1R	Causes, Evaluation, and Repair of Cracks in Concrete Structures
318-99	Building Code Requirements for Structural Concrete and Commentary
364.1R	Guide for Evaluation of Concrete Structures Prior to Rehabilitation
437R	Strength Evaluation of Existing Concrete Buildings
440R-96	State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures
440.1R	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
503R	Use of Epoxy Compounds with Concrete
503.4	Standard Specification for Repairing Concrete with Epoxy Mortars
546R	Concrete Repair Guide

American National Standards Institute (ANSI)

Z-129.1	Hazardous Industrial Chemicals Precautionary Labeling

American Society for Testing and Materials (ASTM)

D 696	Test Method for Coefficient of Linear Thermal Expansion of Plastics Between –30 °C and 30 °C
D 2240	Test Method for Rubber Hardness—Durometer Hardness
D 2583	Test Method for Indentation Hardness of Rigid Body Plastics by Means of a Barcol Impressor
D 3039	Test Method for Tensile Properties of Fiber Resin Composites
D 3165	Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single Lap Joint Laminated Assemblies
D 3418	Test Method for Transition Temperatures of Polymers by Thermal Analysis (DTA or DSC)
D 3528	Test Method for Strength Properties of Double Lap Shear Adhesive Joints by Tension Loading
D 4065	Practice for Determining and Reporting Dynamic Mechanical Properties of Plastics
D 4541	Test Method for Pull off Strength of Coatings Using Portable Adhesion Tester
E 84	Test Method for Surface Burning Characteristics of Building Materials
E 119	Standard Test Methods for Fire Tests of Building Construction and Materials

Canadian Standards Association (CSA)

CSA S806-02	Design and Construction of Building Components with Fiber-Reinforced Polymers

Code of Federal Regulations

CFR 16, Part 1500	Hazardous Substances and Articles; Administration and Enforcement Regulations
CFR 49, Chapter C	Transportation

International Conference of Building Officials (ICBO)

AC125	Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Composite Systems

International Concrete Repair Institute (ICRI)

ICRI 03730	Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion
ICRI 03733	Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces

International Federation for Structural Concrete

FIB 2001	Externally Bonded FRP Reinforcement for RC Structures

These publications may be obtained from these organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American National Standards Institute
11 West 42nd Street
New York, NY 10036

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428

Canadian Standards Association
178 Rexdale Blvd.
Toronto, ON
M9W 1R3 Canada

Code of Federal Regulations
Government Printing Office
732 N. Capitol St. N.W.
Washington, D.C. 20402

International Conference of Building Officials
5360 Workman Mill Road
Whittier, CA 90601-2298

International Concrete Repair Institute
3166 S. River Road Suite 132
Des Plains, IL 60018

International Federation for Structural Concrete
Case Postale 88
CH–1015 Lausanne, Switzerland

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Table A1.1—Typical tensile properties of fibers used in FRP systems

	Elastic modulus		Ultimate strength		Rupture strain, minimum, %
Fiber type	10^3 ksi	GPa	10^3 ksi	GPa	
Carbon					
General purpose	32 to 34	220 to 240	300 to 550	2050 to 3790	1.2
High strength	32 to 34	220 to 240	550 to 700	3790 to 4820	1.4
Ultra-high strength	32 to 34	220 to 240	700 to 900	4820 to 6200	1.5
High modulus	50 to 75	340 to 520	250 to 450	1720 to 3100	0.5
Ultra-high modulus	75 to 100	520 to 690	200 to 350	1380 to 2400	0.2
Glass					
E-glass	10 to 10.5	69 to 72	270 to 390	1860 to 2680	4.5
S-glass	12.5 to 13	86 to 90	500 to 700	3440 to 4140	5.4
Aramid					
General purpose	10 to 12	69 to 83	500 to 600	3440 to 4140	2.5
High performance	16 to 18	110 to 124	500 to 600	3440 to 4140	1.6

Table A1.2—Tensile properties of FRP laminates with fiber volumes of 40 to 60%

	Young's modulus		Ultimate Tensile strength		Rupture strain at 0 degrees, %
	Property at 0 degrees	Property at 90 degrees	Property at 0 degrees	Property at 90 degrees	
FRP-system description (fiber orientation)	10^3 ksi (GPa)	10^3 ksi (MPa)	ksi (MPa)	ksi (MPa)	
High-strength carbon/epoxy, degrees					
0	15 to 21 (100 to 140)	0.3 to 1 (2 to 7)	150 to 350 (1020 to 2080)	5 to 10 (35 to 70)	1.0 to 1.5
0/90	8 to 11 (55 to 76)	8 to 11 (55 to 75)	100 to 150 (700 to 1020)	100 to 150 (700 to 1020)	1.0 to 1.5
+45/–45	2 to 4 (14 to 28)	2 to 4 (14 to 28)	25 to 40 (180 to 280)	25 to 40 (180 to 280)	1.5 to 2.5
E-glass/epoxy, degrees					
0	3 to 6 (20 to 40)	0.3 to 1 (2 to 7)	75 to 200 (520 to 1400)	5 to 10 (35 to 70)	1.5 to 3.0
0/90	2 to 5 (14 to 34)	2 to 5 (14 to 35)	75 to 150 (520 to 1020)	75 to 150 (520 to 1020)	2.0 to 3.0
+45/–45	2 to 3 (14 to 21)	2 to 3 (14 to 20)	25 to 40 (180 to 280)	25 to 40 (180 to 280)	2.5 to 3.5
High-performance aramid/ epoxy, degrees					
0	7 to 10 (48 to 68)	0.3 to 1 (2 to 7)	100 to 250 (700 to 1720)	5 to 10 (35 to 70)	2.0 to 3.0
0/90	4 to 5 (28 to 34)	4 to 5 (28 to 35)	40 to 80 (280 to 550)	40 to 80 (280 to 550)	2.0 to 3.0
+45/–45	1 to 2 (7 to 14)	1 to 2 (7 to 14)	20 to 30 (140 to 210)	20 to 30 (140 to 210)	2.0 to 3.0

Notes:
FRP composite properties are based on FRP systems having an approximate fiber volume of 50% and a composite thickness of 0.1 in. (2.5 mm). In general, precured systems have fiber volumes of 40 to 60%, while wet layup systems have fiber volumes of 25 to 40%. Because the fiber volume influences the gross-laminate properties, precured laminates usually have higher mechanical properties than laminates created using the wet layup technique.

Zero degrees represents unidirectional fiber orientation.

Zero/90 degrees (or +45/–45 degrees) represents fiber balanced in two orthogonal directions, where 0 degrees is the direction of loading, and 90 degrees is normal to the direction of loading.

Tension is applied to 0 degrees direction.

APPENDIXES

APPENDIX A—MATERIAL PROPERTIES OF CARBON, GLASS, AND ARAMID FIBERS

Table A1.1 presents ranges of values for the tensile properties for carbon, glass, and aramid fibers. The tabulated values are based on the testing of impregnated fiber yarns or strands in accordance with Suppliers of Advanced Composite Materials Association test method 16-90. The strands or fiber yarns are impregnated with resin, cured, and then tested in tension. The tabulated properties are calculated using the area of the fibers; the resin area is ignored. Hence, the properties listed in Table A1.1 are representative of unidirectional FRP systems whose properties are reported using net-fiber area (Section 3.3.1).

Table A1.2 presents ranges of tensile properties for CFRP, GFRP, and AFRP laminates with fiber volumes of approximately 40 to 60%. Properties are based on gross-laminate area (Section 3.3.1). The properties are shown for unidirectional, bidirectional, and +45/–45 degree fabrics. Table A1.2 also shows the effect of varying the fiber orientation on the 0 degree strength of the laminate.

Table A1.3 gives the tensile strengths of some commercially available FRP systems. The strength of unidirectional laminates is dependent on fiber type and dry fabric weight.

These tables are not intended to provide ultimate strength values for design purposes.

APPENDIX B—SUMMARY OF STANDARD TEST METHODS

ASTM test methods that quantify the structural behavior of FRP systems bonded to concrete are in preparation. Certain existing ASTM test methods are applicable to the

Table A1.3—Ultimate tensile strength[*] of some commercially available FRP systems

FRP-system description (fiber type/saturating resin/fabric type)	Fabric weight		Ultimate strength[†]	
	oz/yd^3	g/m^3	lb/in.	kN/mm
General purpose carbon/epoxy unidirectional sheet	6	200	2600	500
	12	400	3550	620
High-strength carbon/epoxy unidirectional sheet	7	230	1800	320
	9	300	4000	700
	18	620	5500	960
High-modulus carbon/epoxy unidirectional sheet	9	300	3400	600
General-purpose carbon/epoxy balanced sheet	9	300	1000	180
E-glass/epoxy unidirectional sheet	27	900	4100	720
	10	350	1300	230
E-glass/balanced fabric	9	300	680	120
Aramid/epoxy unidirectional sheet	12	420	4000	700
High-strength carbon/epoxy precured, unidirectional laminate	70[‡]	2380[‡]	19,000	3300
E-glass/vinyl ester precured, unidirectional shell	50[‡]	1700[‡]	9000	1580

[*] Values shown should not be used for design.

[†] Ultimate tensile strength per unit width of sheet or fabric.

[‡] Precured laminate weight.

FRP material. FRP materials can be tested in accordance with the methods listed in Table B1.1 as long as all exceptions to the method are listed in the test report. Durability-related tests use the same test methods but require application specific preconditioning of specimens. Acceptance of the data generated by the listed test methods can be the basis for FRP-material system qualification and acceptance.

Table B1.1—Test methods for FRP-material systems

FRP form	Property	Test method
Sheet and prepreg	Tensile strength, strain elastic modulus	ISIS, ASTM D 3039
	Sheet to sheet-adhesive shear	ISIS
	Sheet to concrete-adhesive shear	ISIS
	Sheet to concrete-adhesive tension	ISIS
	Coefficient of thermal expansion	ASTM D 696
	Glass-transition temperature	ASTM D 4065
	Surface hardness	ASTM D 2583, D 2240, D 3418
	Hoop-ring strength	ISIS
Flat stock	Tensile strength, strain, elastic modulus	ISIS, ASTM D 3039
	Flatstock to flatstock-adhesive shear	ISIS, ASTM D 3165, D 3528
	Flatstock to concrete-adhesive shear	ISIS
	Flatstock to concrete-adhesive tension	ISIS
	Coefficient of thermal expansion	ASTM D 696
	Glass-transition temperature	ASTM D 4065
	Surface hardness	ASTM D 2583, D 2240, D 3418
Pre-molded shell	Tensile strength, strain, elastic modulus	ISIS, ASTM D 3039
	Shell to shell-adhesive shear	ISIS, ASTM D 3165, D 3528
	Shell to concrete-adhesive shear	ISIS
	Shell to concrete-adhesive tension	ISIS
	Coefficient of thermal expansion	ASTM D 696
	Glass-transition temperature	ASTM D 4065

APPENDIX C—AREAS OF FUTURE RESEARCH

As pointed out in the body of the document, future research is needed to provide information in areas that are still unclear or are in need of additional evidence to validate performance. The list of topics presented in this appendix has the purpose of providing a summary.

Materials

- Confirmation of normal (Gaussian) distribution representing the tensile strength of a population of FRP strengthening systems;
- Methods of fireproofing FRP strengthening systems;
- Behavior of FRP strengthened members under elevated temperatures;
- Behavior of FRP strengthened members under cold temperatures;
- Fire rating of concrete members reinforced with FRP bars;
- Effect of different coefficients of thermal expansion between FRP systems and member substrates;
- Creep-rupture behavior and endurance times of FRP systems; and
- Strength and stiffness degradation of FRP systems in harsh environments.

Flexure/axial force

- Compression behavior of noncircular members wrapped with FRP systems;
- Behavior of members strengthened with FRP systems oriented in the direction of the applied axial load;
- Refinement of effective strain for flexure;
- Effects of concrete strength on behavior of FRP strengthened members;
- Effects of lightweight concrete on behavior of FRP strengthened members;
- Behavior of flexural members with tension and compression FRP reinforcement;
- Maximum crack width and deflection prediction and control of concrete reinforced with FRP systems; and
- Long-term deflection behavior of concrete flexural members reinforced with FRP systems.

Shear

- Concrete contribution to shear resistance of members strengthened with FRP systems;
- Effective strain of FRP systems that do not completely wrap around the section; and
- Use of FRP systems for punching shear reinforcement in two-way systems.

Detailing

- Performance of FRP anchors.

The design guide specifically indicated that test methods are needed to determine the following properties of FRP bars:

- Bond characteristics and related bond-dependent coefficients;
- Creep-rupture and endurance times;
- Fatigue characteristics;
- Coefficient of thermal expansion;
- Shear strength; and
- Compressive strength.

ANNEX 8: EXEMPLES APLICACIÓ

Reforç Túnel

Reforç Biga a Flexió

Reforç Pilar

Reforç de Llosa de Forjat

ANNEX 9: “PUNT VERD” GESTIÓ RESIDUS

Què és un Punt verd?

Els punts verds serveixen per desfer-nos dels residus que no podem llençar als contenidors que trobem al carrer. Utilitzant els punts verds contribuïm a millorar el procés de reciclatge i ajudem a preservar el medi ambient.

Punt verd de zona

Punt verd de barri

Punt verd mòbil

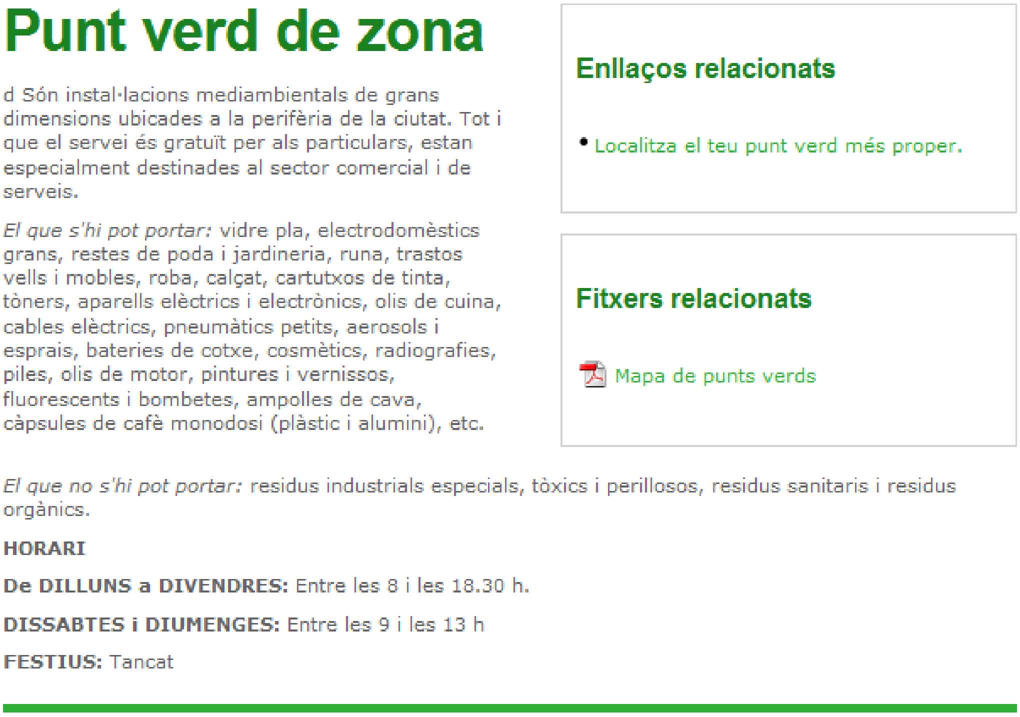
Punt verd mòbil escolar i elèctric

Enllaços relacionats

- Localitza el teu punt verd més proper.

Fitxers relacionats

Mapa de punts verds



Punt verd de zona

d Són instal·lacions mediambientals de grans dimensions ubicades a la perifèria de la ciutat. Tot i que el servei és gratuït per als particulars, estan especialment destinades al sector comercial i de serveis.

El que s'hi pot portar: vidre pla, electrodomèstics grans, restes de poda i jardineria, runa, trastos vells i mobles, roba, calçat, cartutxos de tinta, tòners, aparells elèctrics i electrònics, olis de cuina, cables elèctrics, pneumàtics petits, aerosols i esprais, bateries de cotxe, cosmètics, radiografies, piles, olis de motor, pintures i vernissos, fluorescents i bombetes, ampolles de cava, càpsules de cafè monodosi (plàstic i alumini), etc.

El que no s'hi pot portar: residus industrials especials, tòxics i perillosos, residus sanitaris i residus orgànics.

HORARI

De DILLUNS a DIVENDRES: Entre les 8 i les 18.30 h.

DISSABTES i DIUMENGES: Entre les 9 i les 13 h

FESTIUS: Tancat

Enllaços relacionats

- Localitza el teu punt verd més proper.

Fitxers relacionats

Mapa de punts verds

Troba el teu Punt Verd a BCN

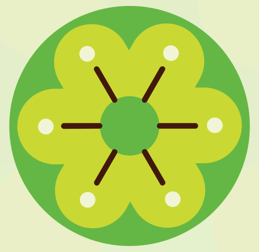
apunta't un punt

Tan important és
qui recicla
com qui separa
bé els residus

900 226 226
el telèfon del civisme

Per a avisos, incidències i suggeriments
Telèfon gratuït
Horari: de dilluns a diumenge
de 8 a 22 h

Telèfon 010: Establiment: 0,47 €. Cost/min: 0,06 €. Tarifat per segons. IVA inclòs.
Missatges de text curt per a persones amb discapacitat auditiva: 93 489 00 98.



Tan important és
qui recicla
com qui separa
bé els residus

bcn.cat/
habitaturba
twitter.com/Bcn_mediambient
telèfon: 010 (24h)

Ajuntament de
Barcelona

---

apunta't un punt

Consulta en aquesta taula el Punt més adient per reciclar cada tipus de residu.

RESIDU	TRACTAMENT DEL RESIDU	P. VERD DE ZONA	P. VERD DE BARRI	P. VERD MÒBIL
Aerosols i esprais	Si estan buits han d'anar al contenidor groc, si no es porten als Punts Verds per recuperar el propel·lent que contenen (principi actiu de l'aerosol) i es tracten adequadament.	Z	B	M
Aparells elèctrics i electrònics	S'hi inclou qualsevol aparell amb piles o amb un endoll: telèfons, calculadores, petits electrodomèstics i, fins i tot, joguines elèctriques. Se'n recuperen els elements: plàstics i metalls.	Z	B	M
Ampolles de cava	Es netegen i es reutilitzen. Així, s'aconsegueix un gran estalvi energètic i de matèries primeres.	Z	B	M
Bateries de cotxe	Es neutralitza l'àcid que contenen i se separen el plàstic i els metalls pesants, com el plom, per reciclar-los.	Z	B	M
Cables	Se separa el plàstic del metall per reciclar-los.	Z	B	M
Calçat	El Programa Roba Amiga, en què participen empreses d'inserció, recupera calçat usat.	Z	B	M
Càpsules de cafè monodosi	Se separen les restes de cafè de les càpsules d'alumini o de plàstic. Les càpsules es reciclen per fer nou alumini o plàstic i del cafè se'n fa compost.	Z	B	M
Cartró de grans dimensions	Se'n fa pasta de paper per obtenir nou paper o cartró. Reciclar-lo permet estalviar energia i aigua i reduir la contaminació.	Z		
Cartutxos de tinta i tòners	Si estan en bon estat, s'omplen per tornar-los a fer servir. Si no ho estan, es reciclen.	Z	B	M
CD i DVD	Els CD estan fets d'un plàstic anomenat policarbonat, que es recupera per fer altres productes de plàstic, després de netejar-ne la tinta de les caràtules.	Z	B	M
Cintes de vídeo i cassets	Se separa el plàstic de les parts metàl·liques per reciclar-lo.	Z	B	M
Complements de vestir	El Programa Roba Amiga, en què participen empreses d'inserció, recupera complements de vestir usats.	Z	B	M
Cosmètics	Se'n recicla l'envàs. El contingut es tracta segons les seves característiques.	Z	B	M
Electrodomèstics grans (rentadores, frigorífics…)	Se'n separen els diferents materials i es tracta el CFC (gas d'efecte hivernacle).	Z		
Ferralla domèstica petita (paelles, cassoles…)	Se'n recuperen els diferents materials metàl·lics, que es fonen per fer objectes nous.	Z	B	M
Fibrociment amb amiant (només al PVZ de Vall d'Hebron)	Plaques de sostre, jardineres, petits dipòsits, canonades... Es porten a un dipòsit controlat. Abans de manipular-ho, truca al 010.	Z		
Filtres de vehicles	Se'n separen les diferents fraccions: acer, plàstic, paper, etc., per reciclar-les.	Z	B	M
Fitosanitaris, herbicides i pesticides	Se'n recicla l'envàs. El contingut es tracta segons les seves característiques.	Z	B	M
Fluorescents i bombetes	Se'n separen i se'n reciclen la part metàl·lica i el vidre. En el cas dels fluorescents i de les bombetes de baix consum també es recupera la pols de mercuri.	Z	B	M
Fusta, trastos i mobles: persianes, sofàs…	Se'n separen les diferents fraccions per reciclar-les o valoritzar-les.	Z		
Matalassos	Se'n separen les diferents fraccions: tèxtils, làtex, acer…, per reciclar-les o valoritzar-les.	Z		
Metalls: alumini, acer inoxidable, plom…	Se'n recuperen els diferents materials metàl·lics, que es fonen per fer objectes nous.	Z	B	M
Olis de cuina	Es reciclen per fer biodièsel.	Z	B	M
Olis de motor	Es regeneren per reutilitzar-los com a oli base en la fabricació de lubricants.	Z	B	M
Piles	Contenen substàncies altament contaminants, com el mercuri. Se'n separen els diferents components: plàstics, paper i, en especial, metalls i mercuri.	Z	B	M
Pintures, coles, vernissos, dissolvents…	Se'n recicla l'envàs. El contingut es tracta segons les seves característiques.	Z	B	M
Plàstic: galledes, garrafes...	Es recicla per formar nou plàstic.	Z		
Pneumàtics petits	Es reutilitzen com a component de capes asfàltiques i paviments de goma o se'n produeix energia mitjançant un procés de valorització.	Z	B	M
Porexpan net*	Se'n recicla el 100% per tornar a fer-ne porexpan.	Z	B	
Radiografies	Contenen sals de plata i altres substàncies contaminants. Se separen per recuperar-les.	Z	B	M
Restes de poda i jardineria	Es transformen en adob a les plantes de compostatge.	Z		
Restes de productes de neteja	Se'n recicla l'envàs. El contingut es tracta segons les seves característiques.	Z	B	M
Roba	El Programa Roba Amiga, en què participen empreses d'inserció, recupera roba usada.	Z	B	M
Runa	Segons les característiques que tingui, es porta a dipòsits controlats o a plantes de reciclatge.	Z		
Termòmetres	També s'hi inclouen productes molt tòxics com el benzè, residus mercurials, residus de laboratori... El contingut es tracta segons les seves característiques.	Z	B	M
Televisors i monitors	Se'n recuperen i se'n reciclen els elements: metalls, plàstics i vidre. La pols fosforescent s'aspira i es tracta separadament.	Z	B	M
Vidre pla, miralls, finestres...	Se separa el vidre dels altres materials: ferro, alumini, plom... El vidre es recicla per obtenir nou vidre i els altres materials es recuperen.	Z		

*Només es recull als PV de Zona i PV de Barri ampliats.

---

apunta't un punt

La millor xarxa de punts

A BCN tens una àmplia xarxa de Punts Verds perquè puguis reciclar tots els residus que no pots llençar als contenidors marrons, grisos, blaus, grocs o verds.

Aprofita aquesta xarxa per contribuir a la millora del procés de reciclatge de la ciutat i ajudar a preservar el medi ambient.

Coneix els quatre tipus de Punts Verds o deixalleries

B

Punt Verd de Barri*
Són instal·lacions mediambientals de proximitat, situades en els barris de la ciutat, destinades a la recollida de residus de menys volum. Actualment hi ha **23 Punts Verds de Barri** que afavoreixen la cultura del reciclatge.

Z

Punt Verd de Zona
Són **instal·lacions mediambientals de grans dimensions** situades a la perifèria de la ciutat. Actualment tens **7 Punts Verds de Zona** a la teva disposició.

M

Punt Verd Mòbil
Una flota de camions amb més de **90 parades** en diferents punts de la ciutat, perquè triïs la que et quedi més a prop.

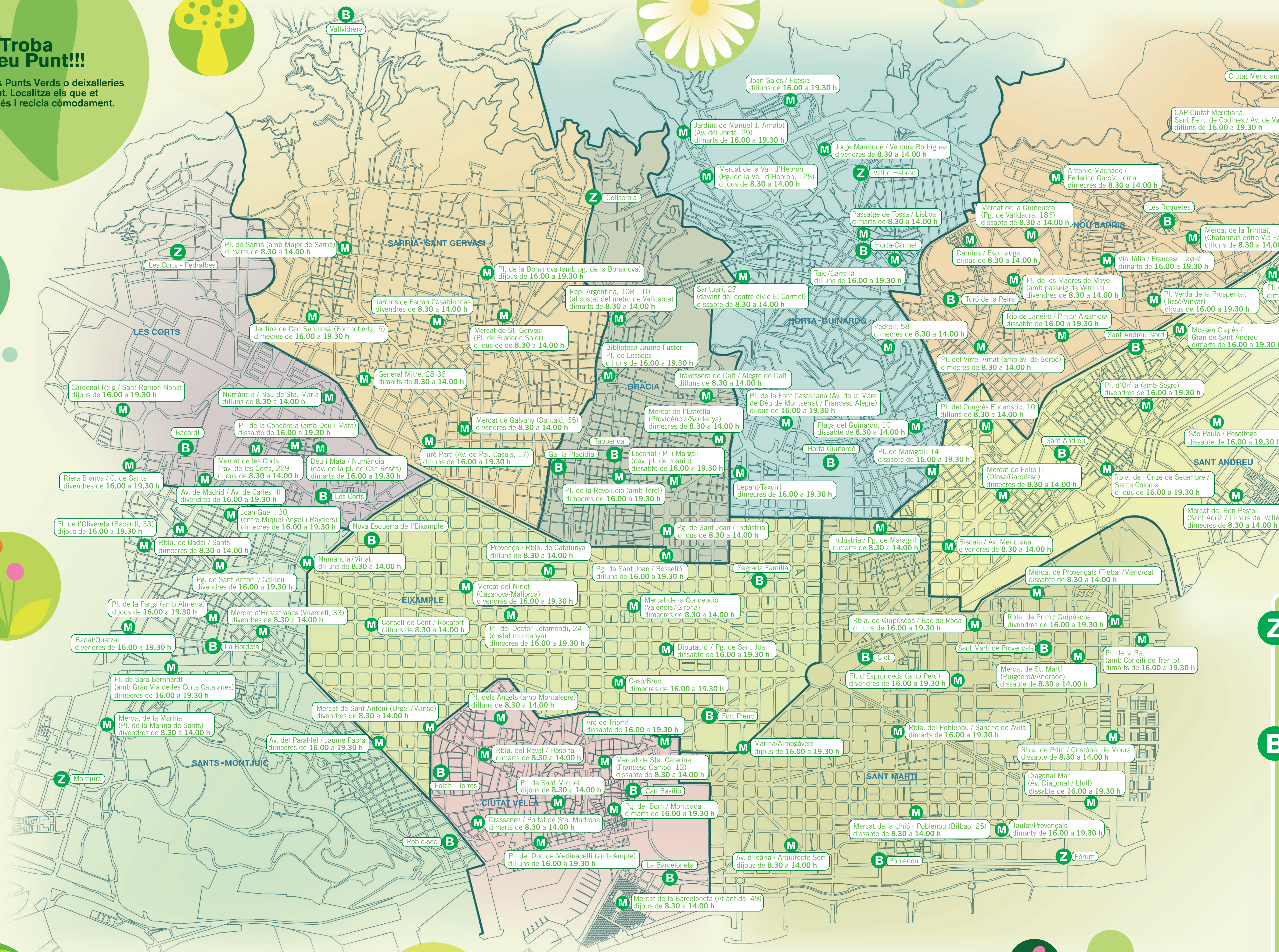
***Els Punts Verds de Barri ampliats són:**

- *LES CORTS*
- *HORTA-CARMEL*
- *LES ROQUETES*
- *POBLENOU*
- *LA BARCELONETA*
- *SANT ANDREU NORD*
- *SAGRADA FAMÍLIA*

Punt Verd Mòbil Escolar
És un Punt Verd Mòbil a **disposició de les escoles** i **altres equipaments** per fer que els alumnes i els ciutadans prenguin consciència ambiental. Actualment, tenim **2 Punts Verds Mòbils** a la teva disposició (www.bcn.cat/mediambient).

Troba el teu Punt!!!

Aquests són els Punts Verds o deixalleries de la ciutat. Localitza els que et convinguin més i recicla còmodament.



Direcció a direcció

Z

Collserola
Collserola, 2, amb passeig de la Vall d'Hebron, Rda. De Dalt, Sortida 6

Fòrum
Avda. del Litoral, 115, Rda. Litoral, lateral mar, Sortida 24, passat Josep Pla

Les Corts - Pedralbes
Avda. d'Esplugues amb Gran Capità

Montjuïc
Foc, 56, cantonada amb Cobalt

Sant Andreu
Caracas, 46, entre Potosí i Tucumán

Vall d'Hebron
Avda. de l'Estat de Catalunya, 23, amb Camí de Can Travi

Vallbona
Castelladrall, 14

De DILLUNS a DIVENDRES	DISSABTES i DIUMENGES	FESTIUS
De **8** a **18:30**h	De **9** a **13**h	Tancat

B

Clot
Parc del Clot, Escultors Claperós davant de Coronel Sanfeliu

Vallvidrera
Reis Catòlics al costat de l'escola Nabí

Gal·la Placídia
Pl. de Gal·la Placídia amb Travessera de Gràcia

Horta - Guinardó
Mas Casanovas davant de l'entrada del pàrquing de l'Hospital de Sant Pau

Horta - Carmel
Dante Alighieri amb C/ de les Lletres

Turó de la Peira
Pg. de la Peira, 1

Les Roquetes
C. de les Torres amb Aiguablava

Ciutat Meridiana
Costabona, 4, al costat del Mercat de Ciutat Meridiana

Sant Andreu
Sant Ildefons cantonada amb Rovira Virgili

Sant Andreu Nord
Pl. de Miquel Casablancas i Joanico amb Bartrina

Poblenou
Carmen Amaya amb Llacuna

La Barceloneta***
Pg. de Salvat Papasseit, 1 al costat de la Fàbrica del Sol

Poble-sec
Pl. de les Tres Xemeneies a la banda de Palaudàries

Folch i Torres
Pl. de Josep M. Folch i Torres amb Reina Amàlia

Sant Martí de Provençals
Andrade, 154

Can Basilio (col·laborador)**
Jaume Giralt, 49, baixos

Les Corts
Nicaragua amb Marquès de Sentmenat

Bacardí
Jardins de Bacardí, Comandant Benitez amb Travessera de les Corts

Sagrada Familia
Lepant, 281-283

Fort Pienc
Alí Bei cantonada amb Sicília

La Bordeta
Jardins de Celestina Vigneaux amb Corral

Nova Esquerra de l'Eixample
Jardins de Montserrat, Còrsega amb Rocafort

Tabuenca (col·laborador)*
Guilleries, 24

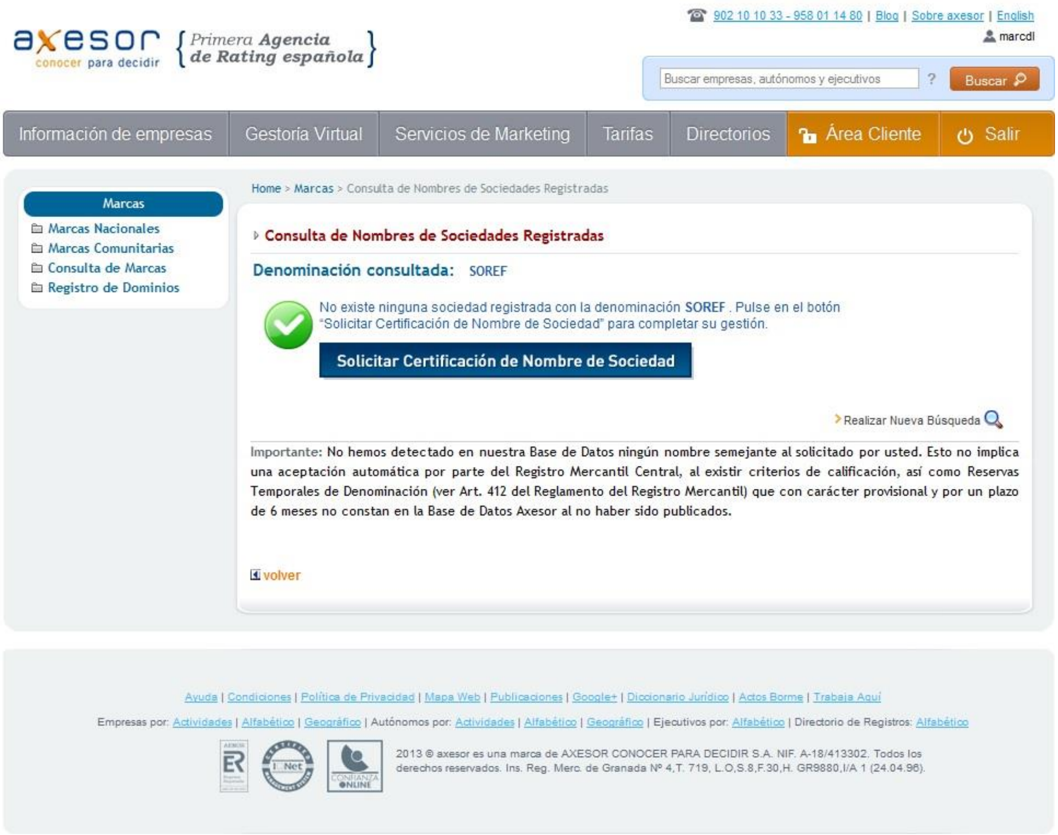
De DILLUNS a DISSABTE*	DIUMENGES i FESTIUS
De **8:30** a **14**h i de **16** a **19:30**h	Tancat

**Tabuenca: de dilluns a divendres, de 8:30 a 13:30h i de 16:00 a 19:00 h, i dissabtes, de 10:00 a 13.00h. Del 24 de juny al 24 de setembre, dissabtes tancat. La setmana següent a la Festa Major de Gràcia el PVC també romandrà tancat.*

*** Can Basilio: de dilluns a divendres, de 10:00 a 13.30h i de 16:30 a 19:30h, i dissabtes, de 10:00 a 13:30h. Del 24 de juny al 24 de setembre, dissabtes tancat.*

**** Previsió de posada en servei: primer trimestre de 2013.*

ANNEX 10: COMPROVANT NOM SOCIETAT DISPONIBLE



Consulta de Nombres de Sociedades Registradas

Denominación consultada: SOREF

No existe ninguna sociedad registrada con la denominación **SOREF** . Pulse en el botón "Solicitar Certificación de Nombre de Sociedad" para completar su gestión.

Importante: No hemos detectado en nuestra Base de Datos ningún nombre semejante al solicitado por usted. Esto no implica una aceptación automática por parte del Registro Mercantil Central, al existir criterios de calificación, así como Reservas Temporales de Denominación (ver Art. 412 del Reglamento del Registro Mercantil) que con carácter provisional y por un plazo de 6 meses no constan en la Base de Datos Axesor al no haber sido publicados.

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Consulta de Nombres de Sociedades Registradas

Denominación consultada: SOREF

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Importante: No hemos detectado en nuestra Base de Datos ningún nombre semejante al solicitado por usted. Esto no implica una aceptación automática por parte del Registro Mercantil Central, al existir criterios de calificación, así como Reservas Temporales de Denominación (ver Art. 412 del Reglamento del Registro Mercantil) que con carácter provisional y por un plazo de 6 meses no constan en la Base de Datos Axesor al no haber sido publicados.

ANNEX 11: COMPETIDORS PRIMERA ETAPA

BASF

http://www.basf.es/ecp1/Spain/es/

BASF és l'empresa química líder mundial: The Chemical Company. Oferim solucions intel·ligents i productes d'alta qualitat als nostres clients.

Les empreses del grup BASF a la Península Ibèrica fabriquen productes químics per ajudar els seus clients a tenir més èxit en pràcticament qualsevol sector de la indústria. Actualment, BASF comercialitza a Espanya la seva extensa gamma de productes a través de set empreses i una joint venture, en què treballen més de 2.000 col·laboradors. Cinc d'elles disposen de centres de producció propis. A Portugal, comptem amb dues empreses en quatre localitzacions diferents.

MBrace®, refuerzo de estructuras

El sistema de refuerzo de estructuras de la mano de un gran equipo: BASF

Reparar y reforzar estructuras actualmente se ha convertido en una necesidad. Dichos trabajos requieren un alto conocimiento de las técnicas y de los productos para evitar que vuelvan a aparecer problemas en un futuro. El sistema MBrace® ofrece la posibilidad de reforzar estructuras con una serie de ventajas impensables con otros sistemas pero sólo con el apoyo de un gran equipo como el ofrecido por BASF, los resultados podrán ser óptimos. Los años de experiencia, el conocimiento del sistema, el nivel de desarrollo de los productos y el apoyo técnico y humano en la prescripción y en el cálculo hacen de BASF y del SISTEMA MBrace®, un referente en el mercado de la reparación y del refuerzo.

Vea nuestros productos

MBrace® LAMINATE CF

Laminado preformado de fibra de carbono para refuerzo de elementos estructurales

» Ver más sobre MBrace® LAMINATE CF

MBrace® FIBRE

Fibras de refuerzo de carbono o aramida (Kevlar®*).

» Ver más sobre MBrace® FIBRE

» Ver todos los productos

Vea nuestras obras más destacadas

Estación Internacional de Canfran

Rehabilitación y refuerzo estructural

» Ver Estación Internacional de Canfran

Reparación Palacio Iturri de Elorrio

MBrace Laminado, EMACO S88 TIXOTROPICO y CONCRESIVE 4000.

» Ver Reparación Palacio Iturri de Elorrio

» Ver todas las obras

MBrace® LAMINATE CF

Laminado preformado de fibra de carbono para refuerzo de elementos estructurales

Campo de Aplicación

- Aplicable sobre soportes de hormigón, metálicos y de madera.
- Refuerzo tracción elementos flexionados con adhesión en superficie.
- Errores de proyecto o ejecución.
- Mejoras estructurales o modificaciones debidas a cambios de usos o cambios de exigencia en normativas.
- Mejora del control de la fisuración y de la resistencia a impactos y ondas expansivas.
- Las aplicaciones más habituales de refuerzo son: vigas, puentes, losas, forjados en tableros de puentes, estructuras y superficies de aparcamientos, refuerzo de muros, depósitos, etc.

Propiedades

- Reducido peso. No es preciso apuntalar.
- Excelente relación resistencia/peso.
- Total orientación de la fibra gracias a la matriz epoxi.
- Bajo espesor de aplicación.
- Elevada capacidad de carga.
- Excelente resistencia química.
- Fácil y rápidamente aplicable.

MBrace® FIBRE

Fibras de refuerzo de carbono o aramida (Kevlar®*).

Campo de Aplicación

Fibra de carbono

- Refuerzos a tracción en elementos flexionados, sometidos a cortante y confinando a compresión.
- Errores de proyecto o ejecución.
- Mejoras estructurales o modificaciones debidas a cambios de usos o cambios de exigencia en normativas.
- Mejora del control de la fisuración y de la resistencia a impactos y ondas expansivas.
- Trabajos de reparación en general.

Propiedades

- Elevada ligereza. No se precisa apuntalamiento del sistema.
- Reducido espesor del sistema.
- Fácilmente aplicable.

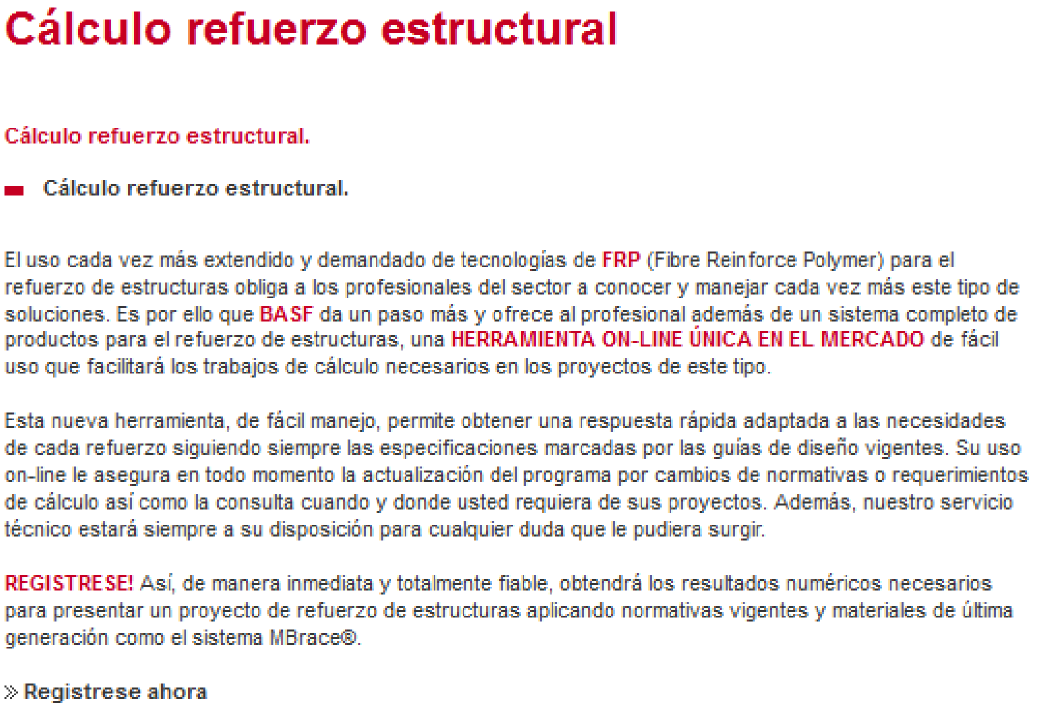
Fibras de carbono:

- Elevadas resistencias a tracción.
- Orientación unidireccional.
- Presentación en módulo elástico análogo al acero y en alto módulo.
- Elevada resistencia química.
- Puede cortarse con facilidad con una tijera normal.

Fibra aramida (Kevlar®):

- **Orientación unidireccional.**
- **Elevada resistencia al impacto.**
- **Bajo módulo, óptimo para refuerzos en mampostería y piedra.**

» **Descargar ficha técnica** (
» **Volver a Productos**
» **Obras relacionadas con MBra**



Cálculo refuerzo estructural

Cálculo refuerzo estructural.

- **Cálculo refuerzo estructural.**

El uso cada vez más extendido y demandado de tecnologías de FRP (Fibre Reinforce Polymer) para el refuerzo de estructuras obliga a los profesionales del sector a conocer y manejar cada vez más este tipo de soluciones. Es por ello que BASF da un paso más y ofrece al profesional además de un sistema completo de productos para el refuerzo de estructuras, una HERRAMIENTA ON-LINE ÚNICA EN EL MERCADO de fácil uso que facilitará los trabajos de cálculo necesarios en los proyectos de este tipo.

Esta nueva herramienta, de fácil manejo, permite obtener una respuesta rápida adaptada a las necesidades de cada refuerzo siguiendo siempre las especificaciones marcadas por las guías de diseño vigentes. Su uso on-line le asegura en todo momento la actualización del programa por cambios de normativas o requerimientos de cálculo así como la consulta cuando y donde usted requiera de sus proyectos. Además, nuestro servicio técnico estará siempre a su disposición para cualquier duda que le pudiera surgir.

REGISTRESE! Así, de manera inmediata y totalmente fiable, obtendrá los resultados numéricos necesarios para presentar un proyecto de refuerzo de estructuras aplicando normativas vigentes y materiales de última generación como el sistema MBrace®.

» **Registrese ahora**

SIKA

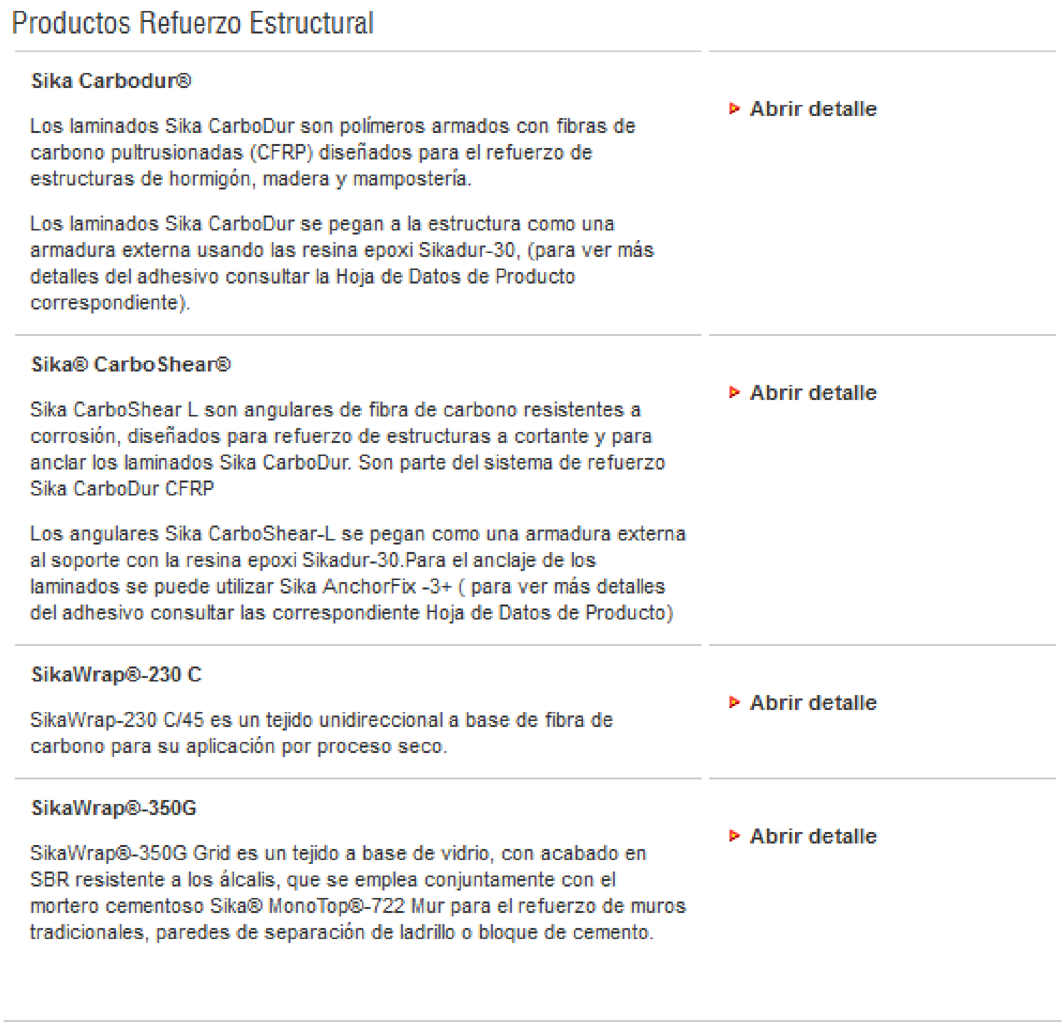
http://esp.sika.com/es/group.html

Sika desenvolupa solucions orientades al futur en construccions de primer nivell, optimitzant els processos dels clients i reduint els seus costos. El ràpid subministrament de productes innovadors i serveis de qualitat garantida arreu del món són factors clau de l'èxit, que ha permès a Sika arribar a taxes de creixement per sobre de la mitjana en mercats difícils i el desembarcament reeixit en nous mercats.

La divisió de construcció de Sika està repartida en tres unitats de negoci:

- Aplicadors
- Productors de Formigó
- Distribució

Sika té equips tècnics i de vendes específics en contacte directe amb els clients en cada fase de la construcció. D'aquesta manera s'assegura una qualitat perfecta i una satisfacció completa.



Productos Refuerzo Estructural

Sika Carbodur®

Los laminados Sika CarboDur son polímeros armados con fibras de carbono pultrusionadas (CFRP) diseñados para el refuerzo de estructuras de hormigón, madera y mampostería.

Los laminados Sika CarboDur se pegan a la estructura como una armadura externa usando las resina epoxi Sikadur-30, (para ver más detalles del adhesivo consultar la Hoja de Datos de Producto correspondiente).

▸ **Abrir detalle**

Sika® CarboShear®

Sika CarboShear L son angulares de fibra de carbono resistentes a corrosión, diseñados para refuerzo de estructuras a cortante y para anclar los laminados Sika CarboDur. Son parte del sistema de refuerzo Sika CarboDur CFRP

Los angulares Sika CarboShear-L se pegan como una armadura externa al soporte con la resina epoxi Sikadur-30.Para el anclaje de los laminados se puede utilizar Sika AnchorFix -3+ (para ver más detalles del adhesivo consultar las correspondiente Hoja de Datos de Producto)

▸ **Abrir detalle**

SikaWrap®-230 C

SikaWrap-230 C/45 es un tejido unidireccional a base de fibra de carbono para su aplicación por proceso seco.

▸ **Abrir detalle**

SikaWrap®-350G

SikaWrap®-350G Grid es un tejido a base de vidrio, con acabado en SBR resistente a los álcalis, que se emplea conjuntamente con el mortero cementoso Sika® MonoTop®-722 Mur para el refuerzo de muros tradicionales, paredes de separación de ladrillo o bloque de cemento.

▸ **Abrir detalle**

MAPEI

http://www.mapei.com/es-es/

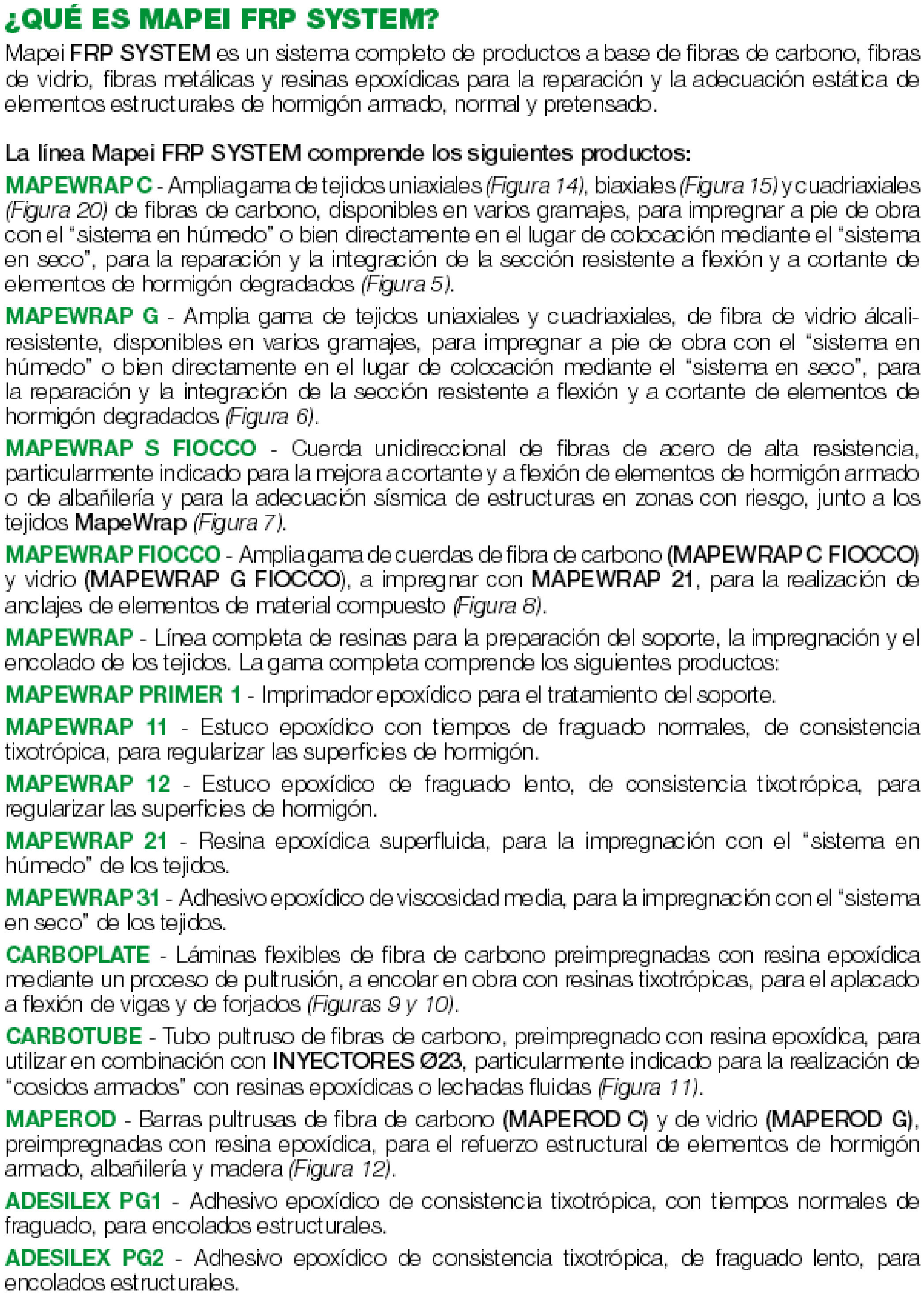
Fundada a Milà en 1937, Mapei és avui el líder mundial en la producció d'adhesius i productes químics per a la construcció.

A partir de 1960 Mapei va iniciar la seva estratègia d'internacionalització per aconseguir una major proximitat a les exigències locals i una reducció al mínim dels costos de transport.

Actualment el Grup està format per 65 subsidiàries, amb 62 fàbriques en els 5 continents operant en 30 països diferents, cadascun dels quals està dotat d'un laboratori de control de qualitat.

Mapei sempre ha dedicat grans esforços en la investigació, invertint en R + D el 12% dels seus recursos humans i el 5% de la facturació total de la companyia de la qual, en particular, el 70% va dirigida al desenvolupament de productes eco sostenibles, que respecten el medi ambient i compleixen els requisits del programa LEED.

A més, Mapei ha desenvolupat una xarxa tecnicocomercial que opera a tot el món i ofereix un eficaç servei d'Assistència Tècnica, molt apreciat per arquitectes, enginyers, contractistes i propietaris.



¿QUÉ ES MAPEI FRP SYSTEM?

Mapei **FRP SYSTEM** es un sistema completo de productos a base de fibras de carbono, fibras de vidrio, fibras metálicas y resinas epoxídicas para la reparación y la adecuación estática de elementos estructurales de hormigón armado, normal y pretensado.

La línea Mapei FRP SYSTEM comprende los siguientes productos:

MAPEWRAP C - Amplia gama de tejidos uniaxiales *(Figura 14)*, biaxiales *(Figura 15)* y cuadriaxiales *(Figura 20)* de fibras de carbono, disponibles en varios gramajes, para impregnar a pie de obra con el "sistema en húmedo" o bien directamente en el lugar de colocación mediante el "sistema en seco", para la reparación y la integración de la sección resistente a flexión y a cortante de elementos de hormigón degradados *(Figura 5)*.

MAPEWRAP G - Amplia gama de tejidos uniaxiales y cuadriaxiales, de fibra de vidrio álcali-resistente, disponibles en varios gramajes, para impregnar a pie de obra con el "sistema en húmedo" o bien directamente en el lugar de colocación mediante el "sistema en seco", para la reparación y la integración de la sección resistente a flexión y a cortante de elementos de hormigón degradados *(Figura 6)*.

MAPEWRAP S FIOCCO - Cuerda unidireccional de fibras de acero de alta resistencia, particularmente indicado para la mejora a cortante y a flexión de elementos de hormigón armado o de albañilería y para la adecuación sísmica de estructuras en zonas con riesgo, junto a los tejidos **MapeWrap** *(Figura 7)*.

MAPEWRAP FIOCCO - Amplia gama de cuerdas de fibra de carbono **(MAPEWRAP C FIOCCO)** y vidrio **(MAPEWRAP G FIOCCO)**, a impregnar con **MAPEWRAP 21**, para la realización de anclajes de elementos de material compuesto *(Figura 8)*.

MAPEWRAP - Línea completa de resinas para la preparación del soporte, la impregnación y el encolado de los tejidos. La gama completa comprende los siguientes productos:

MAPEWRAP PRIMER 1 - Imprimador epoxídico para el tratamiento del soporte.

MAPEWRAP 11 - Estuco epoxídico con tiempos de fraguado normales, de consistencia tixotrópica, para regularizar las superficies de hormigón.

MAPEWRAP 12 - Estuco epoxídico de fraguado lento, de consistencia tixotrópica, para regularizar las superficies de hormigón.

MAPEWRAP 21 - Resina epoxídica superfluida, para la impregnación con el "sistema en húmedo" de los tejidos.

MAPEWRAP 31 - Adhesivo epoxídico de viscosidad media, para la impregnación con el "sistema en seco" de los tejidos.

CARBOPLATE - Láminas flexibles de fibra de carbono preimpregnadas con resina epoxídica mediante un proceso de pultrusión, a encolar en obra con resinas tixotrópicas, para el aplacado a flexión de vigas y de forjados *(Figuras 9 y 10)*.

CARBOTUBE - Tubo pultruso de fibras de carbono, preimpregnado con resina epoxídica, para utilizar en combinación con **INYECTORES Ø23**, particularmente indicado para la realización de "cosidos armados" con resinas epoxídicas o lechadas fluidas *(Figura 11)*.

MAPEROD - Barras pultrusas de fibra de carbono **(MAPEROD C)** y de vidrio **(MAPEROD G)**, preimpregnadas con resina epoxídica, para el refuerzo estructural de elementos de hormigón armado, albañilería y madera *(Figura 12)*.

ADESILEX PG1 - Adhesivo epoxídico de consistencia tixotrópica, con tiempos normales de fraguado, para encolados estructurales.

ADESILEX PG2 - Adhesivo epoxídico de consistencia tixotrópica, de fraguado lento, para encolados estructurales.

BETEC

http://www.betec.es/home

Els Productes BETEC compten amb més de trenta anys d'experiència. BETEC s'ha especialitzat en la investigació, desenvolupament, fabricació, distribució i posada en obra de morters especials i productes químics per a la construcció.

Sempre a l'avantguarda entre les empreses del sector, BETEC ha estat pionera en la fabricació a Espanya de morters d'altes resistències sense retracció i de tota una gamma de productes auxiliars per a la reparació del formigó, que van millorar ostensiblement les tècniques de construcció emprades i aconseguint que BETEC avui dia, sigui capaç d'aportar les solucions tecnològicament més avançades per a l'obra civil, l'edificació, el manteniment, la indústria i la rehabilitació.

Des del 12 de maig de l'any 2.010 BETEC passa a formar part de Propamsa SAU, empresa del Grup Cementos Molins, com la divisió de productes especials. Tant des Propamsa com des BETEC, l'objectiu principal és la satisfacció dels nostres clients, garantint les solucions més avançades i anticipant-nos a les seves necessitats.

Per això, comptem amb una àmplia gamma de productes i solucions que compleixen els més alts estàndards per qualitat i tecnologia. De la unió d'esforços de les dues empreses pretenem oferir al mercat una major gamma de productes i un millor servei.

BETEC CARBOCOMP TEXTIL

Tejido de Fibra de Carbono para refuerzo de estructuras.

BETEC CARBOCOMP TEXTIL es un sistema basado en el empleo de tejido unidireccional de fibra de carbono (CFRP) de gran resistencia mecánica a la tracción, para el refuerzo de estructuras de hormigón,acero, fábrica de ladrillo y madera.

CPE

http://www.consultoracpe.com/refuerzos_fibra.php

CPE compta amb un departament dedicat a la cada vegada mes important especialització de reforços d'estructures existents emprant làmines de fibra de carboni i resines amb base epoxídica fabricats per l'empresa SIKA .... Dins d'aquest departament disposes de personal especialitzat en el càlcul d'aquest tipus de reforços així com d'instal·ladors homologats per l'empresa subministradora dels reforços.

En tractar-se d'un tipus de reforços de relativament jove implantació en el mercat de les rehabilitacions a nivell nacional, es requereix per a la correcta utilització de la supervisió dels treballs per part d'un grup d'enginyers qualificat i amb experiència, i això és precisament el que CPE ofereix, avalats per la seva experiència en l'àmbit del càlcul estructural.

El correcte ús d'aquests elements, comporta l'estudi expert de cada projecte, per tal de poder valorar l'adequació o no d'aquesta tipologia de reforç per a cada cas concret, ja que com sempre en estructures no es tracta només de calcular el reforç necessari sinó de saber per a cada situació especial, que classe de reforç s'adapta millor tant des del punt de vista econòmic, com de l'estructural i arquitectònic.

CPE

CONSULTORA DE PROYECTOS Y ESTRUCTURAS S.L

ANNEX 12: COMPETIDORS SEGONA ETAPA

CARBON CONCRETE

http://www.carbonconcrete.es/

Carbon Concrete SL, és una empresa especialitzada en el reforç d'estructures de formigó amb fibra de carboni, oferint una **gestió integral en l'àmbit de la reparació i reforç estructural** . En aquest camp, realitza les funcions de consultoria d’enginyeria i gestiona l'execució de l'obra. Oferim solucions en la rehabilitació d'estructures que requereixen d'una intervenció perquè segueixin oferint els estàndards de seguretat i durabilitat recollits en les normatives vigents en el nostre país.

SERVEIS

L'empresa està especialitzada en el tractament de patologies i reforços d'estructures amb fibra de carboni. Els nostres serveis engloben l'estudi, disseny i la posada en obra del reforç.

En els camps tant d'edificació com de construcció civil, donem resposta a la solució de patologies d'origen químic i mecànic. El tractament de les patologies inclou l'assessorament, i el tractament complet amb els productes més adequats, i el reforç mitjançant el sistema de fibra de carboni.

Comptem amb un equip tècnic especialitzat, format per Enginyer de Camins, Canals, Ports i Enginyer Tècnic d'Obres Públiques a més d'un equip qualificat per a garantir una correcta posada en obra i mitjans tècnics específics.

Casos més habituals de reforç:

- Formigó de qualitat inferior a l’especificada en projecte
- Augment de les sobrecàrregues
- Canvi d'ús
- Corrosió d'armadures
- Errors d'armat en pilars, bigues, forjats,…
- Errors de projecte

Zones per a reforços:

- Bigues i biguetes
- Lloses
- Forjats unidireccionals
- Forjats reticurals

- Pilars

L'ús de fibra de carboni com a substitutiu de l'acer, ens aporta avantatges com l'absència de corrosió, una mínima càrrega morta a l'estructura, curt temps d'intervenció i afectació a l'obra. Al ser un producte molt lleuger, permet manipular-lo amb les mans i s'adhereix sense necessitat d' apuntalar, si bé les seves propietats són clarament superiors a l'acer tradicional. La reducció en el cost global d'aplicació d'un reforç de fibra de carboni (producte més mà d'obra i maquinària) es situa entorn al 30-40% davant d'un reforç tradicional.

CARBONCONCRETE
REFUERZO DE ESTRUCTURAS DE HORMIGÓN

NOVAPOX

http://www.novapox.com/

NOVAPOX és una societat del sector de la construcció creada al març de 1997, fruit de l'associació d'un grup de professionals amb una dilatada experiència de més de 20 anys en el camp de les aplicacions tècniques, principalment en el camp de les reparacions i reforços estructurals.

La missió de NOVAPOX és ser una empresa de rehabilitació d'edificis líder al sector, oferint la màxima qualitat de treball en totes les àrees: equip tècnic, administració, producció i direcció general, amb una visió molt clara, ser una empresa capdavantera en el món de la rehabilitació i, concretament, en el món de la química aplicada a la construcció, fent servir tècniques innovadores i, al mateix temps, mantenint l'essència d'una empresa de rehabilitació tradicional.

Posem a disposició dels nostres clients una Gestió Integral del projecte facilitant un desenvolupament "claus en mà" del mateix a través de la interlocució amb els nostres tècnics.

El nostre equip tècnic d'Arquitectes, Arquitectes Tècnics i Enginyers podran assegurar la qualitat al llarg de tot el projecte responent a les necessitats que el client ens sol · liciti o bé prenent iniciativa i decisions sobre la intervenció puntual o la rehabilitació total a l'edifici. Els mateixos tècnics, arquitectes i enginyers, coordinen i supervisen les obres des de l'inici de l'encàrrec fins al final realitzant:

- Anàlisi i diagnòstic de conservació de l'edifici.
- Redacció de documentació tècnica. Projecte.
- Confecció de pressupost de les obres.
- Sol·licitud de permisos d'obra i tramitació de subvencions.
- Execució del projecte.
- Lliurament i liquidació d'obra.

NOVAPOX SL

Constructora Tècnica, Consulting

ORION GRUPO

http://www.oriongrupo.com/default.asp

Amb més de 18 anys dedicats al sector de la reparació, reforç i impermeabilització d'estructures de formigó, Orion Reparació estructural SL és una de les empreses pioneres en aquest camp.

Amb infinitat d'obres realitzades en tota la geografia nacional Orion pot ser considerada l'empresa líder en la rehabilitació d'obres d'edificació, obra pública o enginyeria civil.

La recerca de la millora contínua i la col · laboració amb els nostres clients, fan de la nostra empresa el soci de referència per als clients privats o les administracions públiques, aportant en cada cas la solució més òptima per a cada problema.

Tècnicament avançats

Dins la política d'Orion sempre aquesta la incorporació de les més modernes tecnologies al nostre servei, que ens aportin una diferenciació de la competència i més ens ajudin en la millora de la competitivitat de l'empresa.

Amb aquesta finalitat Orion ha estat capaç d'incorporar en els seus sistemes de producció la maquinària més moderna i els sistemes de treball més avançats. Per tot això som líders en reforços a base de fibra de carboni o aramida, protecció catòdica d'estructures de formigó, restauració i rehabilitació d'edificis històrics o la solució de patologies estructurals.

Per aconseguir uns objectius de satisfacció del client òptims i uns nivells de seguretat en obra superiors hem implantat els sistemes de qualitat i seguretat basats en les normes internacionals ISO 9001:2008 i OSHAS 18001:2007 sent empresa certificada en ambdues normes.

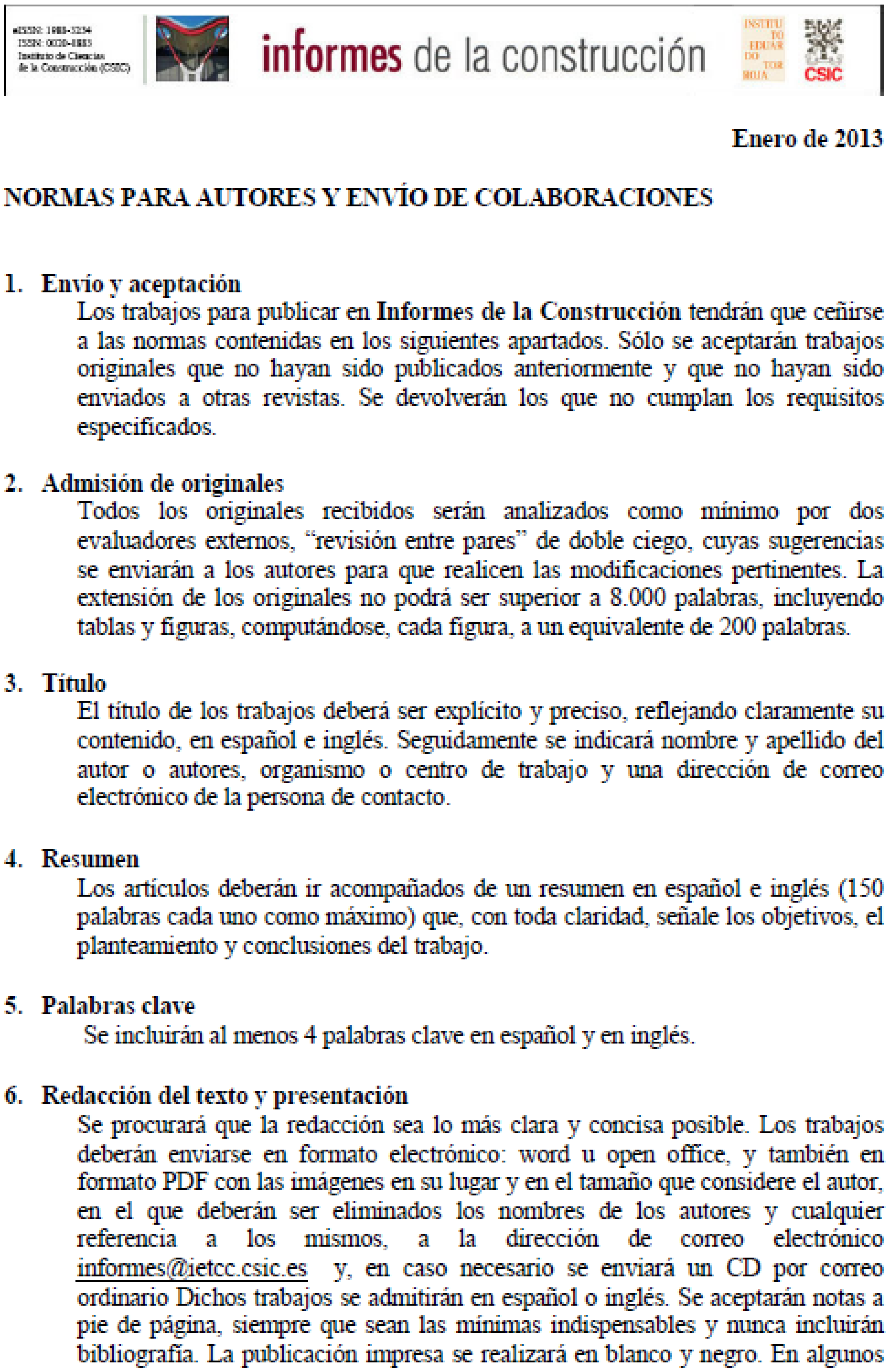
Tecnologia al seu servei

Dins de la política de l'empresa, s'ha primat la incorporació de totes aquelles unitats de negoci que aportessin valor afegit a l'empresa, de manera que aquestes àrees de negoci en aquests moments suposen el major percentatge de facturació de l'empresa.

L'especialització en tot tipus de reforços, l'execució de substitució d'aparells de suport en ponts, la incorporació de diferents sistemes de protecció d'estructures, etc. fan que Orion es trobi a l'avantguarda en les tècniques de reparació, reforç, impermeabilització i protecció d'estructures.

ORION
REPARACIÓN ESTRUCTURAL S.L
La química aplicada en la construcción

ANNEX 13: NORMES ARTICLE "INFORMES DE LA CONSTRUCCIÓN"



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Instituto de Ciencias
de la Construcción (CSIC)

informes de la construcción

CSIC

Enero de 2013

NORMAS PARA AUTORES Y ENVÍO DE COLABORACIONES

1. **Envío y aceptación**
   Los trabajos para publicar en **Informes de la Construcción** tendrán que ceñirse a las normas contenidas en los siguientes apartados. Sólo se aceptarán trabajos originales que no hayan sido publicados anteriormente y que no hayan sido enviados a otras revistas. Se devolverán los que no cumplan los requisitos especificados.

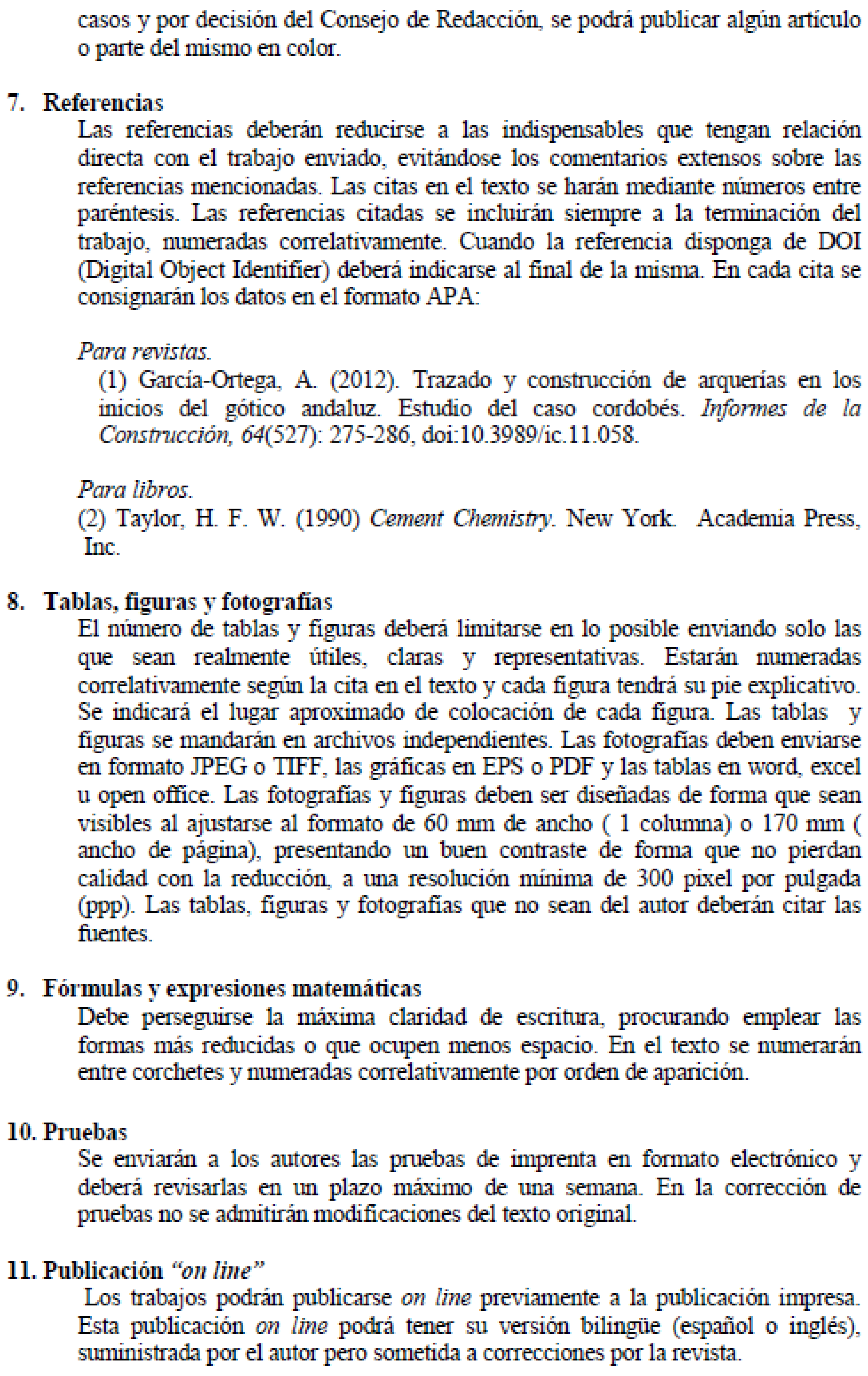
2. **Admisión de originales**
   Todos los originales recibidos serán analizados como mínimo por dos evaluadores externos, "revisión entre pares" de doble ciego, cuyas sugerencias se enviarán a los autores para que realicen las modificaciones pertinentes. La extensión de los originales no podrá ser superior a 8.000 palabras, incluyendo tablas y figuras, computándose, cada figura, a un equivalente de 200 palabras.

3. **Título**
   El título de los trabajos deberá ser explícito y preciso, reflejando claramente su contenido, en español e inglés. Seguidamente se indicará nombre y apellido del autor o autores, organismo o centro de trabajo y una dirección de correo electrónico de la persona de contacto.

4. **Resumen**
   Los artículos deberán ir acompañados de un resumen en español e inglés (150 palabras cada uno como máximo) que, con toda claridad, señale los objetivos, el planteamiento y conclusiones del trabajo.

5. **Palabras clave**
   Se incluirán al menos 4 palabras clave en español y en inglés.

6. **Redacción del texto y presentación**
   Se procurará que la redacción sea lo más clara y concisa posible. Los trabajos deberán enviarse en formato electrónico: word u open office, y también en formato PDF con las imágenes en su lugar y en el tamaño que considere el autor, en el que deberán ser eliminados los nombres de los autores y cualquier referencia a los mismos, a la dirección de correo electrónico informes@ietcc.csic.es y, en caso necesario se enviará un CD por correo ordinario Dichos trabajos se admitirán en español o inglés. Se aceptarán notas a pie de página, siempre que sean las mínimas indispensables y nunca incluirán bibliografía. La publicación impresa se realizará en blanco y negro. En algunos



casos y por decisión del Consejo de Redacción, se podrá publicar algún artículo o parte del mismo en color.

7. Referencias

Las referencias deberán reducirse a las indispensables que tengan relación directa con el trabajo enviado, evitándose los comentarios extensos sobre las referencias mencionadas. Las citas en el texto se harán mediante números entre paréntesis. Las referencias citadas se incluirán siempre a la terminación del trabajo, numeradas correlativamente. Cuando la referencia disponga de DOI (Digital Object Identifier) deberá indicarse al final de la misma. En cada cita se consignarán los datos en el formato APA:

Para revistas.

(1) García-Ortega, A. (2012). Trazado y construcción de arquerías en los inicios del gótico andaluz. Estudio del caso cordobés. *Informes de la Construcción, 64*(527): 275-286, doi:10.3989/ic.11.058.

Para libros.

(2) Taylor, H. F. W. (1990) *Cement Chemistry*. New York. Academia Press, Inc.

8. Tablas, figuras y fotografías

El número de tablas y figuras deberá limitarse en lo posible enviando solo las que sean realmente útiles, claras y representativas. Estarán numeradas correlativamente según la cita en el texto y cada figura tendrá su pie explicativo. Se indicará el lugar aproximado de colocación de cada figura. Las tablas y figuras se mandarán en archivos independientes. Las fotografías deben enviarse en formato JPEG o TIFF, las gráficas en EPS o PDF y las tablas en word, excel u open office. Las fotografías y figuras deben ser diseñadas de forma que sean visibles al ajustarse al formato de 60 mm de ancho (1 columna) o 170 mm (ancho de página), presentando un buen contraste de forma que no pierdan calidad con la reducción, a una resolución mínima de 300 pixel por pulgada (ppp). Las tablas, figuras y fotografías que no sean del autor deberán citar las fuentes.

9. Fórmulas y expresiones matemáticas

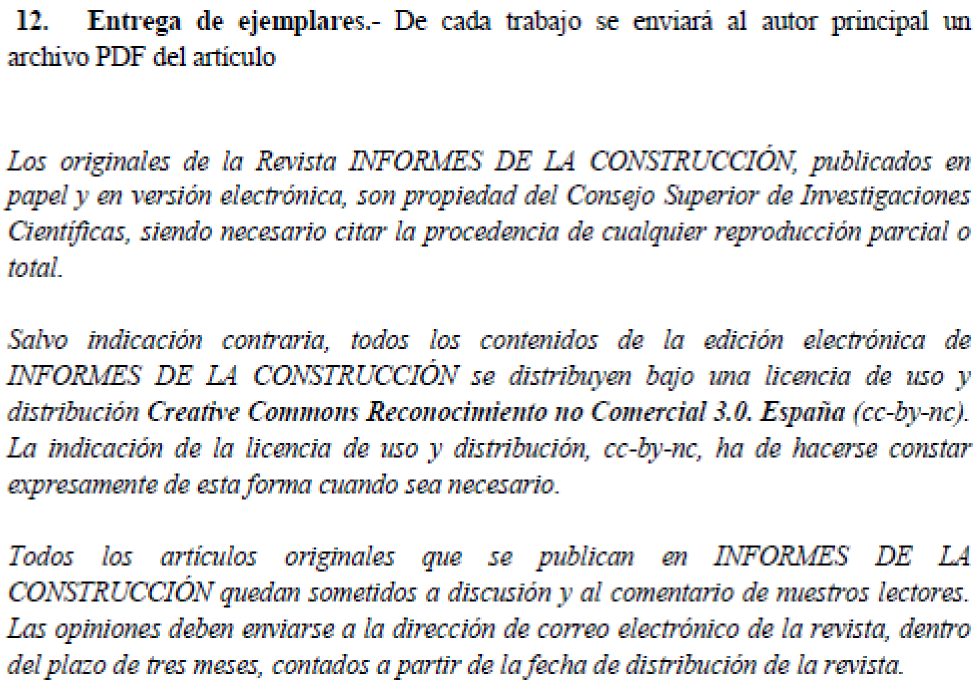
Debe perseguirse la máxima claridad de escritura, procurando emplear las formas más reducidas o que ocupen menos espacio. En el texto se numerarán entre corchetes y numeradas correlativamente por orden de aparición.

10. Pruebas

Se enviarán a los autores las pruebas de imprenta en formato electrónico y deberá revisarlas en un plazo máximo de una semana. En la corrección de pruebas no se admitirán modificaciones del texto original.

11. Publicación *"on line"*

Los trabajos podrán publicarse *on line* previamente a la publicación impresa. Esta publicación *on line* podrá tener su versión bilingüe (español o inglés), suministrada por el autor pero sometida a correcciones por la revista.



12. Entrega de ejemplares.- De cada trabajo se enviará al autor principal un archivo PDF del artículo

Los originales de la Revista INFORMES DE LA CONSTRUCCIÓN, publicados en papel y en versión electrónica, son propiedad del Consejo Superior de Investigaciones Científicas, siendo necesario citar la procedencia de cualquier reproducción parcial o total.

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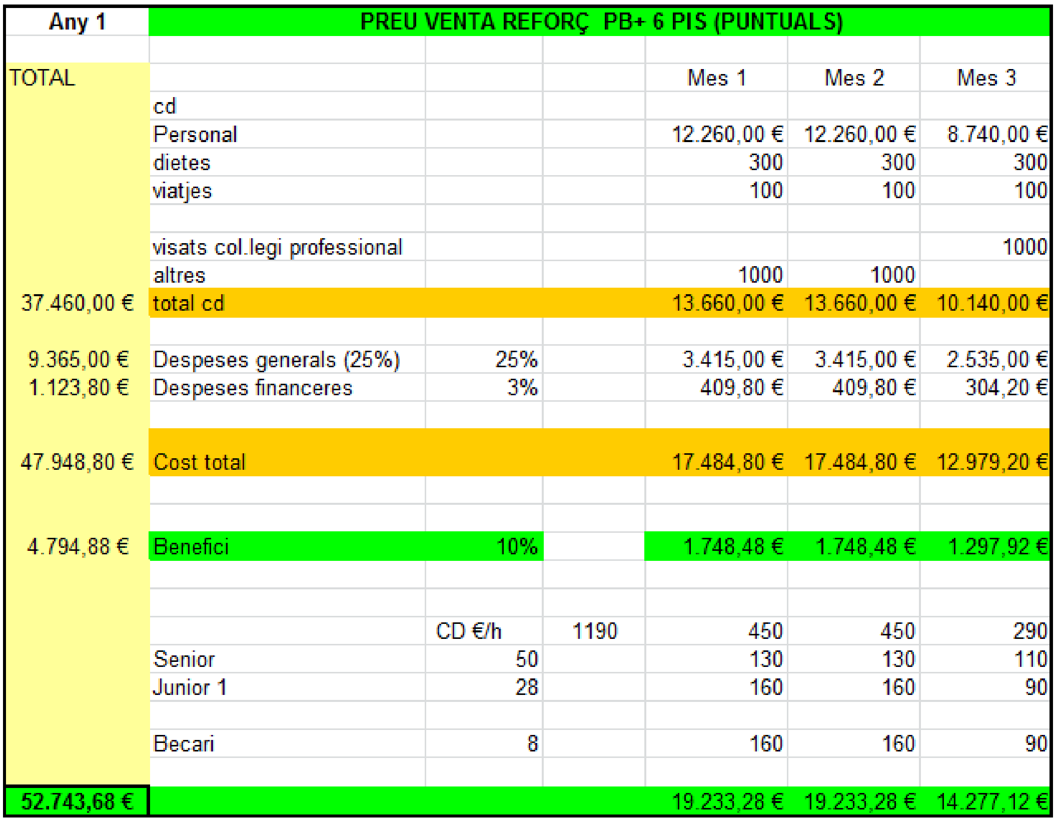
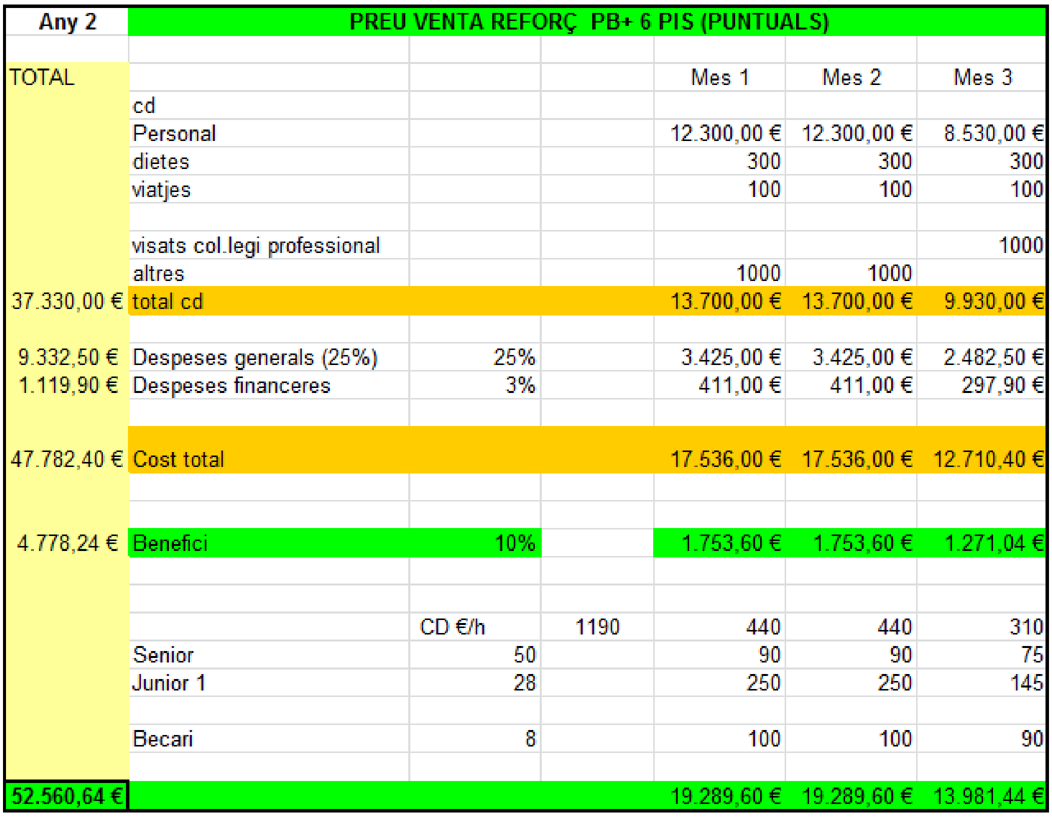
Todos los artículos originales que se publican en INFORMES DE LA CONSTRUCCIÓN quedan sometidos a discusión y al comentario de nuestros lectores. Las opiniones deben enviarse a la dirección de correo electrónico de la revista, dentro del plazo de tres meses, contados a partir de la fecha de distribución de la revista.

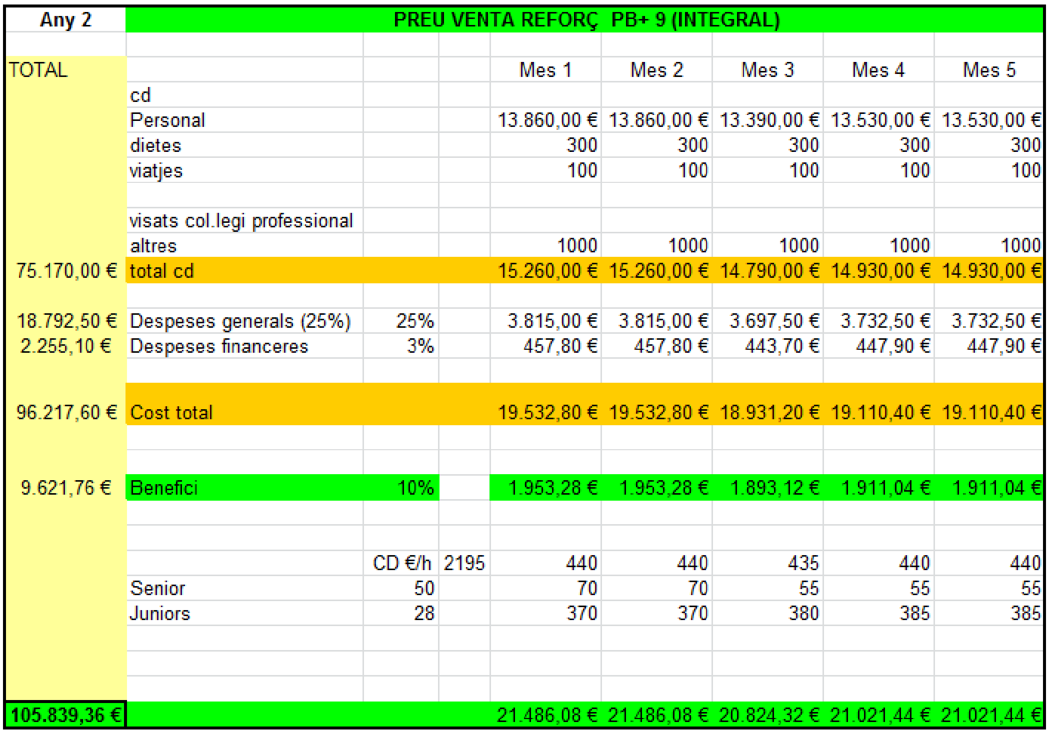
ANNEX 14: CÀLCUL PRESSUPOSTOS



Any 1	**PREU VENTA REFORÇ PB+ 6 PIS (PUNTUALS)**					
TOTAL				Mes 1	Mes 2	Mes 3
	cd					
	Personal			12.260,00 €	12.260,00 €	8.740,00 €
	dietes			300	300	300
	viatjes			100	100	100
	visats col.legi professional					1000
	altres			1000	1000	
37.460,00 €	total cd			13.660,00 €	13.660,00 €	10.140,00 €
9.365,00 €	Despeses generals (25%)	25%		3.415,00 €	3.415,00 €	2.535,00 €
1.123,80 €	Despeses financeres	3%		409,80 €	409,80 €	304,20 €
47.948,80 €	Cost total			17.484,80 €	17.484,80 €	12.979,20 €
4.794,88 €	Benefici	10%		1.748,48 €	1.748,48 €	1.297,92 €
		CD €/h	1190	450	450	290
	Senior	50		130	130	110
	Junior 1	28		160	160	90
	Becari	8		160	160	90
52.743,68 €				19.233,28 €	19.233,28 €	14.277,12 €



Any 2	**PREU VENTA REFORÇ PB+ 6 PIS (PUNTUALS)**					
TOTAL				Mes 1	Mes 2	Mes 3
	cd					
	Personal			12.300,00 €	12.300,00 €	8.530,00 €
	dietes			300	300	300
	viatjes			100	100	100
	visats col.legi professional					1000
	altres			1000	1000	
37.330,00 €	total cd			13.700,00 €	13.700,00 €	9.930,00 €
9.332,50 €	Despeses generals (25%)	25%		3.425,00 €	3.425,00 €	2.482,50 €
1.119,90 €	Despeses financeres	3%		411,00 €	411,00 €	297,90 €
47.782,40 €	Cost total			17.536,00 €	17.536,00 €	12.710,40 €
4.778,24 €	Benefici	10%		1.753,60 €	1.753,60 €	1.271,04 €
		CD €/h	1190	440	440	310
	Senior	50		90	90	75
	Junior 1	28		250	250	145
	Becari	8		100	100	90
52.560,64 €				19.289,60 €	19.289,60 €	13.981,44 €

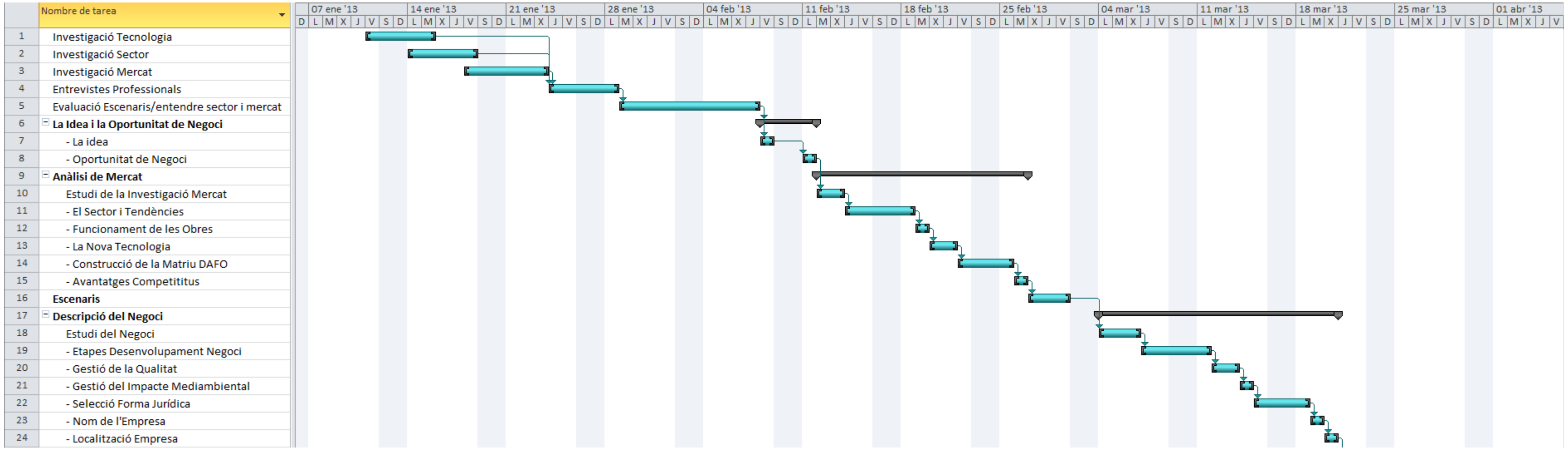


Any 2	**PREU VENTA REFORÇ PB+ 9 (INTEGRAL)**							
TOTAL				Mes 1	Mes 2	Mes 3	Mes 4	Mes 5
	cd							
	Personal			13.860,00 €	13.860,00 €	13.390,00 €	13.530,00 €	13.530,00 €
	dietes			300	300	300	300	300
	viatjes			100	100	100	100	100
	visats col.legi professional							
	altres			1000	1000	1000	1000	1000
75.170,00 €	total cd			15.260,00 €	15.260,00 €	14.790,00 €	14.930,00 €	14.930,00 €
18.792,50 €	Despeses generals (25%)	25%		3.815,00 €	3.815,00 €	3.697,50 €	3.732,50 €	3.732,50 €
2.255,10 €	Despeses financeres	3%		457,80 €	457,80 €	443,70 €	447,90 €	447,90 €
96.217,60 €	Cost total			19.532,80 €	19.532,80 €	18.931,20 €	19.110,40 €	19.110,40 €
9.621,76 €	Benefici	10%		1.953,28 €	1.953,28 €	1.893,12 €	1.911,04 €	1.911,04 €
		CD €/h	2195	440	440	435	440	440
	Senior	50		70	70	55	55	55
	Juniors	28		370	370	380	385	385
105.839,36 €				21.486,08 €	21.486,08 €	20.824,32 €	21.021,44 €	21.021,44 €

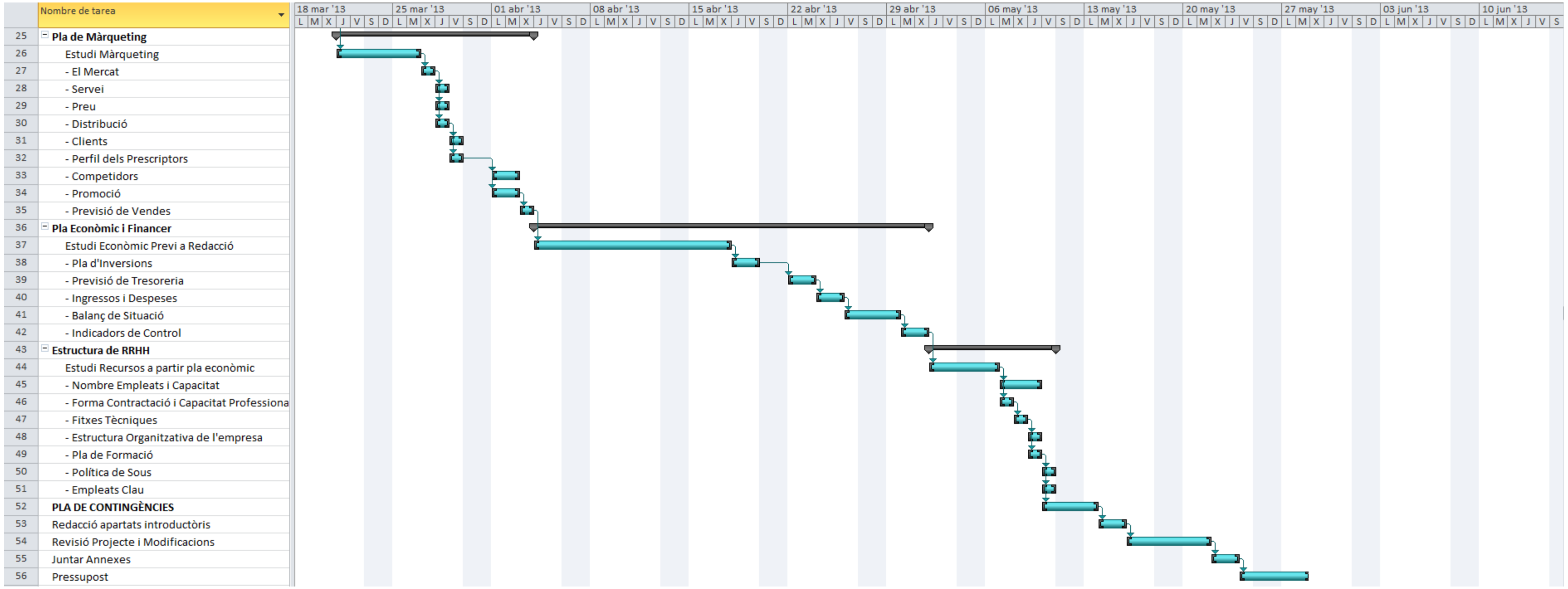
ANNEX 15: PLANIFICACIÓ PROJECTE

Per tal de realitzar al planificació d'aquest projecte s'ha utilitzat l'eina d'ofimàtica Microsoft Project. El fet de fer aquesta planificació ha estat molt útil per assignar temporalment les tasques i poder fer un seguiment en tot moment de les tasques pendents.

Així doncs ens les següent pàgines es mostra el diagrama de Gantt del projecte amb el temps assignat a cada tasca.



	Nombre de tarea
1	Investigació Tecnologia
2	Investigació Sector
3	Investigació Mercat
4	Entrevistes Professionals
5	Evaluació Escenaris/entendre sector i mercat
6	**La Idea i la Oportunitat de Negoci**
7	- La idea
8	- Oportunitat de Negoci
9	**Anàlisi de Mercat**
10	Estudi de la Investigació Mercat
11	- El Sector i Tendències
12	- Funcionament de les Obres
13	- La Nova Tecnologia
14	- Construcció de la Matriu DAFO
15	- Avantatges Competititus
16	**Escenaris**
17	**Descripció del Negoci**
18	Estudi del Negoci
19	- Etapes Desenvolupament Negoci
20	- Gestió de la Qualitat
21	- Gestió del Impacte Mediambiental
22	- Selecció Forma Jurídica
23	- Nom de l'Empresa
24	- Localització Empresa



	Nombre de tarea
25	**Pla de Màrqueting**
26	Estudi Màrqueting
27	- El Mercat
28	- Servei
29	- Preu
30	- Distribució
31	- Clients
32	- Perfil dels Prescriptors
33	- Competidors
34	- Promoció
35	- Previsió de Vendes
36	**Pla Econòmic i Financer**
37	Estudi Econòmic Previ a Redacció
38	- Pla d'Inversions
39	- Previsió de Tresoreria
40	- Ingressos i Despeses
41	- Balanç de Situació
42	- Indicadors de Control
43	**Estructura de RRHH**
44	Estudi Recursos a partir pla econòmic
45	- Nombre Empleats i Capacitat
46	- Forma Contractació i Capacitat Professiona
47	- Fitxes Tècniques
48	- Estructura Organitzativa de l'empresa
49	- Pla de Formació
50	- Política de Sous
51	- Empleats Clau
52	**PLA DE CONTINGÈNCIES**
53	Redacció apartats introductòris
54	Revisió Projecte i Modificacions
55	Juntar Annexes
56	Pressupost