PRACTICAL DESIGN CONSIDERATION

FOR BASE PLATE AND ANCHORAGE CONNECTIONS IN FOUNDATION

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ABSTRACT

PRACTICAL DESIGN CONSIDERATION FOR BASE PLATE AND ANCHORAGE CONNECTIONS IN FOUNDATION

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The purpose of this study about "Practical Design Consideration For Base Plate and Anchorage Connections in Foundation" is to gain an understanding of anchorage, and that anchorage is the most important part of the structure. Each anchorage is bound by a purpose with certain conditions and requirements and finally suitable material means to accomplish it.

The National Building Code of Canada states little about anchor bolts and it leaves its use to the discretion and judgement of the Engineer..

In the first four chapters the writer, Surinder Sachdeva has brought out the facts of technology transfer, history of anchorage, various practical factors which influence reliability, simplicity, economic, and various anchorage systems.

In the design chapter, different methods of designing base plate and anchor bolts are discussed. Also, briefly discussed are major requirements of embedment, tension, shear, and combined loading.

Miscellaneous anchorages required for machine foundation, massive concrete, and other problems pertaining to field complaints are described with suggested details.

Finally, conclusions with respect to major tasks in anchoring systems are discussed.

ACKNOWLEDGEMENTS

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DEDICATION

To my wife Pushpa
and daughter
Shikha Sachdeva

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a = Deflection of bearing plate, distance of the triangular pressure, depth of stress block.

A_o = Surface area of shear cone, in^2.

A_s = Tensile area, in^2.

A_g = Gross area of bolt, in^2.

b = Clear distance from the face of column web to edge of flange, inches.

B = Width of base plate, inches.

C = Constant for concrete type or resultant of compression triangle.

D = Internal dissipation of energy or diameter of bolt.

d = Effective depth distance from the compression face to the center of steel or clear distance between column flanges, inches.

d_h = Head diameter of anchor.

e = Eccentricity of equivalent axial load.

E_s = Young's modulus of elasticity of steel.

E_c = Young's modulus of elasticity of concrete.

F_b = Allowable bending stress in steel.

F_p = Allowable bearing pressure on the supporting material.

f_c' = Concrete compressive strength at 28 days.

f_c = Allowable compressive stress in concrete.

f_s = Tensile strength of steel (k.s.i.).

f_y = Yield strength of anchor steel (k.s.i.).

f_{ut} = Minimum tensile strength of steel.

J = Lever arm ratio (length of lever arm/effective depth) at working loads.

K = Distance from centre of bolt to the point at which the concrete surface and plate make first contact.

k_1	=	Constant for oily thread of bolt.
L	=	Length of base plate, inches.
l_e, l_d	=	Embedment length of bolt in concrete.
M	=	Unfactored moment (k-ft).
M_p	=	Plastic moment.
n	=	Side cover distance or edge distance.
n	=	Maximum overhang cantilever or modular ratio of concrete ($\frac{Es}{Ec}$)
P_d	=	Desired pretension.
P	=	Unfactored axial load.
P_u	=	Ultimate applied tension.
P_{uc}'	=	Ultimate tensile capacity of concrete.
P_{us}'	=	Ultimate tensile capacity of steel.
P_{uc}''	=	Ultimate capacity of bolt in tension at a free edge.
S	=	Section Modulus (in^3).
t	=	Thickness of base plate.
T	=	Applied tension (unfactored).
V	=	Unfactored applied shear.
V_{uc}'	=	Ultimate shear capacity in concrete.
V_{us}'	=	Ultimate shear capacity in steel.
W	=	External work done.
x_t	=	Distance from center line of bolt to the center line of column reinforcement.
x_c	=	Distance from center line of the bolt to face of column.
β	=	Tan ϕ
O	=	Angle between yield line and x-axis or reduction factor.
λ	=	Ratio $\frac{d}{b}$
Ω	=	Distance of load from edge of base plate (+)

CHAPTER - 1

INTRODUCTION

Chapter 1.

INTRODUCTION

The primary functions of all structures are to enclose a certain space and to protect it from the natural elements of wind, rain, earthquake, snow, from changes in temperature etc., depending upon the type of structures and the requirements. Every problem is conditioned by a final purpose, secondly by certain essential conditions to be met, thirdly by secondary requirements. Anchorage is of utmost importance practically in every case where an engineered structure depends on a concrete foundation for support and stability with particular reference to resisting stresses of shear, tension and compression. Perhaps the simplest but at the same time most commonly used form of anchorage in building column is anchor bolt and base plate. Basically the structure must find its support in the ground, forcing it to react in such a way as to keep in equilibrium the group of forces and weights which act on it. When horizontal forces occur, a weight and a balancing arm are required over the support to put them in equilibrium, as the anchorage of the structure to the ground is, in general, a more difficult and costly step. In regards to resistance: keep a balance between the acting forces and the supporting reactions, by internal forces in the structural elements. This must be accomplished with utmost economy and without considering the constructional exigencies, aesthetic and functional reasons. In principle, the structure or anchorage must match the intensities of stresses, minimum of material, thus increasing the safety and sensation of unforced stability of the structure.

1.1 HISTORY OF ANCHOR BOLT

Before the development of Portland cement it was common practice to fasten anchor bolts and plates or other fasteners into drilled holes in rock or masonary, using molten lead or sulphur as the glue. The technicality has changed but very little during the past century and half except that today a more sophisticated type of glue in the form epoxy resin mortar, has replaced the molten lead and sulphur.

In earlier times embedment of anchorages in masonary and rock, other than concrete differed little from current practice. The wrought iron rods, hooks and other devices were built into the masonary or rocks to ensure against the pull out of the fasteners, the big break change came from the general acceptance of Portland cement concrete towards the end of 19th century.

1.2 TECHNOLOGY TRANSFER AND REVIEWING OF CODES

More than 30 years ago the famous American scientist Vannerar Bush wrote that because of the "growing mountain of research" methods of transmitting the results of technology are totally inadequate. Codes and standards can be considered part of the technology transfer process. How can designers be best made aware of the latest research results related to the building technology, the difficulties are great and immense?

Reviewing the design references, it is found that information on base plates and anchor bolts design is very limited. The codes often referred to anchor bolt design are CSA Standard S16.1-M78 "Steel structures of buildings", Limit States Design and C.S.A. Standard A23.3-M77 "Design of concrete structures for buildings".

The reference in C.S. Standard S16.1 is quite small and limited stating that anchor bolts shall be designed to resist the tension forces developed from uplift and bending moments as well as shear forces. The most common concept used for anchor bolt design employs smooth or deformed reinforcing bar with a plate. The load carrying capacity of anchor bolts depend on their arrangement and embedment lengths. CSA Standard 23.3 lists minimum development length for given deformed bars in a straight condition and development length for standard hooks and bends. The design of base plate was controlled by bearing restrictions on concrete, shear was transmitted to the concrete through shear lugs or bars attached to the base plate, and the tensile anchorage steel was generally proportioned only for bending or direct stress. The embedment requirements for anchorage steel were not clearly defined by any code and were left largely to the discretion of the design Engineer. The major building codes governing steel and concrete construction do not specify design formulas for grouted anchor bolt-base plate connection details. In case of large forces in seismic design or nuclear plants above design approach is inefficient, expansive and bad construction details.

The purpose of this report is to review the various problems, the effect of edge conditions, strength of concrete, size, strength, number and spacing of anchors are main requirements to control anchorage.

CHAPTER - 2-

STRUCTURAL SAFETY

AND

RELATED PROBLEMS

Structural Safety and Related Problems

2.1 STRUCTURAL SAFETY

Structural safety is one of the basic requirements of any civil engineering structure. Until about two centuries ago all the structures were designed and built according to experience. A concept was tried and by experience involving collapse or accidents, the design methods were refined until a satisfactory solution was found. The method of design was repeated over and over again perhaps with slight alteration and this passed on generation to generation by the method of apprenticeship. Many imperial rules were developed in this way, some are still used.

Today most of the structures are designed by a more rational direct method involving an understanding of Newtonian mechanics, external loads, material behaviour. The more complex methods of computer and finite elements are used to ensure the structure is sufficiently strong to withstand all the loads applied to it.

Apart from the sound methods of design there is an ever present risk of death or injury from structural collapse due to catastrophic conditions such as major earthquakes, floods, hurricanes and tornados. These collapses still occur apart from all the improvements. But it is not as great as that from building fires or automobile accidents. It is now recognized that deaths or injuries can be prevented drastically by proper design.

To reduce the risk of collapse to an acceptable level, safety factors i.e., ratio between the calculated strength and applied loads are introduced and stipulated in building code and structural standards. Some basic factor of safety specified in National Building Code, 1970 e.g., Overturning (1.5), Sliding (1.5), Bolts (2.5), Foundation (3).

There is now a considerable research effort aimed at basing safety criteria more directly on risk and ultimate failure. It should be noted that errors cause structural collapse, no matter how good safety factors applied, are of little help in preventing collapses.

2.2 ERRORS

Errors leading to collapse are made by those who design, build or use the structure or by those who demolish it or excavate near it. It is very important that people should have the best information and the experience to make use of it.

Building Codes and structural standard specify minimum loads and safety factors and provide the best knowledge at the time of writing. Leaving aside a small conventional structure which is covered by the empirical rules, standards must only be applied by the competent and experienced engineers. Good communication and inspection are tools in preventing errors from occuring. Unclear specifications or contract arrangements, drawings that do not give sufficient detail or inadequate understanding of drawings and specifications cause errors. Lack of communication between the structural engineer and the building or architect is a potential source of trouble.

2.3 PROBLEMS DURING DESIGN

Following are the points which are to be cosidered carefully during design.

a) Wind suctions on roofs on non-engineered buildings, roof panels provide inadequate wind anchorage.

b) Failure in details, sufficient anchorage or bearing distance to allow tne construction tolerance.

c) Failure of connection due to inderterminate forces or impacts.

d) Choice of material for example include the selection of excessive brittle materials, metal subjected to fatigue and fracture due to vibrations and extreme temperature conditions.

e) Assessment of loads due to wind uplift, ponding loads, snow slides, explosions or impact.

2.4 PROBLEMS DURING CONSTRUCTION

A building cannot be manufactured in a shop and then set in place like a piece of furniture in a house. Prefabrication of structural elements, later to be assembled and joined together on the construction site, has been developed in recent years. In Canada this has been a great source of trouble mainly due to lack of erection procedures, proper temporary support, building elements which are themselves, unstable or incapable of resisting loads until the building is completed. Material handling men complained bitterly about the obstructions and interference of the anchor bolt projections.

In the field it is hard to place the anchor bolt in fixed position while placing concrete. Yet fundamentally, the true function of an anchor bolt is its ability to hold to the desired position. Sometimes the crew had to bend them by hammering or even burn them with torches to fit them into the bolt holes. The only effort made so far is to provide sleeves, this merely gives more length and space for bending to fit into the bolt holes but still they have to be bent by hand to the desired fittings.

2.5 PROBLEMS DURING USE

The change of use of structure, alterations, can drastically change the structural capacity. Unwanted collapses during demolition usually occur because of inadequate understanding of structural behaviour.

CHAPTER - 3 -

COLUMN BASES

Chapter - 3 -

COLUMN BASES

3.1 BASE PLATE

In most steel structures, base plates are provided to spread and distribute the column load to the concrete foundation either footing or pedestal. Since the plate is usually larger than the column, bending occurs resulting in compressive bearing stresses in the concrete, they are small at the edges and maximum under the column. Since the column may be of the order of 10 to 20 k.s.i. (68 to 136 MPa) working stress, depending upon the end conditions and slenderness ratio, stress of such a magnitude will simply crush the concrete. This justifies the existence of a base plate, thick and large enough to distribute the load safely from the highly stressed column to the less resistant concrete. For concentric loads methods are suggested in A.I.S.C. and C.I.S. C. Handbooks for calculating the thickness of the base plate. A few comments are forwarded about these mehtods.

The non-uniform stress distribution under the plate due to axial load or movement is a function of flexural behaviour of the plate. The ratio of the area of concrete to that of the plate, which effects confinement and consequently the triaxial stress state in the concrete and the non-linear concrete material behaviour. This complex behaviour results in a rigorous analytical solution. The basis of A.I.S.C. emprirical formula was the result of Shelson's experimental work on plate subject to bending for large ratio of A_c/A_b where A_c is the area of concrete and A_b is the area of base plate. According to Hawkin's investigations base plates designed by A.I.S.C. or C.I.S.C. methods are quite conservative

The method demonstrated in the A.I.S.C. specification produce a unique thickness for a given load, concrete area and concrete compressive strength and thus cannot be used to predict the strength of plates with other thicknesses.

According to John T. Dewolf, test results indicate that recent revisions to the A.I.S.C. specification for the design, fabrication and errection of structural steel buildings is conservative. It is desirable to have larger factors of safety in base plates in columns than for beams and columns. The required plate thickness is given by:

$$t = \sqrt{\frac{3\ Fp \quad x\ n^2}{Fb}} \qquad \text{-----------(1)}$$

Where Fp is allowable bearing pressure on the supporting material, k.s.i.

n = The maximum overhanging cantilever span of the bearing plate.

t = Thickness of bearing plate; inches.

F_b = Allowable bearing stress in bearing plate, k.s.i.

3.1.1 PLATE DEFLECTION

As the size of the plate increases, the deflection becomes larger and portions of the plate which deflect most cannot distribute the assumed uniform loading to the supporting material. Thus portions of the plate which deflect the least must carry a higher load and may overstress the underlying support. Therefore, some limit should be placed upon the deflection on bearing plates. This limit should be a function of the deformability of the supporting material. The equation for deflection of a fixed cantilever under uniform loading can be restated to express the required thickness of a bearing plate as a function of the deflection at the edge of the plate

$$t = \frac{n}{10} \sqrt[3]{\frac{Fp \times n}{20 \times a}}$$ where E_s is assumed to be 30,000 k.s.i. --------(2)

where a is deflection of the bearing plate, in inches. The theoretical analysis of the deflection that should be allowed for various supporting material is beyond the scope of this paper, it is believed that 0.01 inch of upward deflection at the plate edge is reasonable and practical limitation for most bearing plates.

Equation (1) can be restated $Fp = \frac{F_b \times t^2}{3n^2}$ and used to replace Fp in the familiar equation for deflection of a cantilever beam under a uniform load

$$a = \frac{3n^4}{3E_s \times t^2 \times Fp}$$ after rearranging

following equation results:

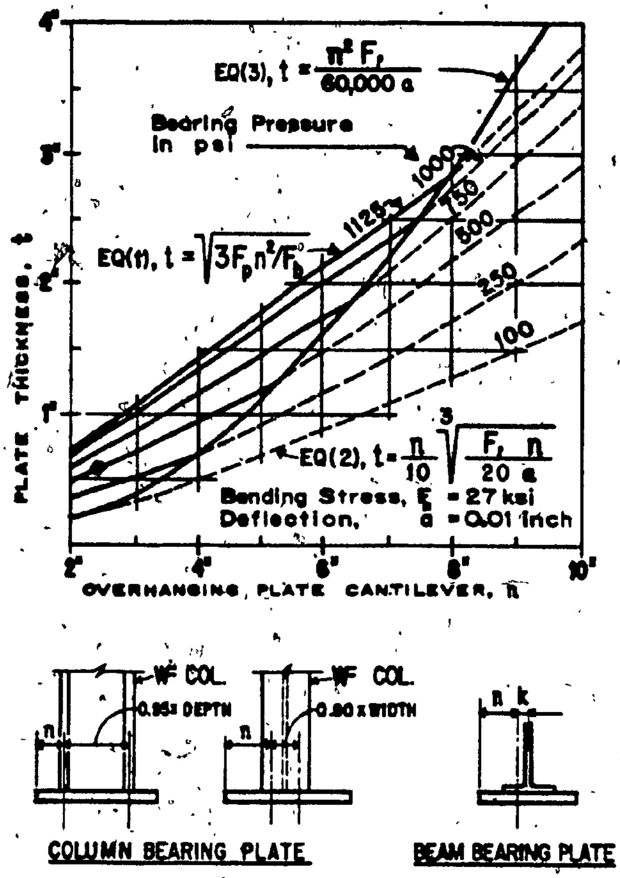
$$t = \frac{n^2 \times F_b}{60{,}000 \times a}$$ --------(3)

where E is assumed to be 30,000 k.s.i.

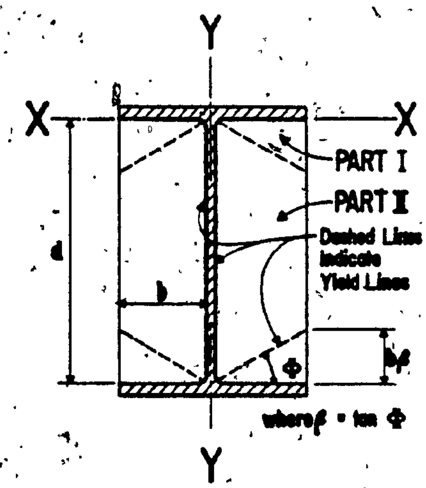
See Figure 1, in which equation 1, 2, 3, can be combined on one graph.

3.1.2 MINIMUM COLUMN BASE PLATE THICKNESS

As the load on the column diminshes, the required base plate thickness approaches the size of the column itself. By A.I.S.C. or C.I.S.C. mehtod of analysis, the overhanging cantilever span and there-



(a)



(b)

BASE PLATE THICKNESS

FIG. 1

fore plate thickness approach zero, obviously, the A.I.S.C. method does not apply in such situations. This problem can be most easily solved by yield line theory. The development of this theory can be found in standard text books on structural design by R.H. Wood, Plates and Elastic Design of Slabs and Plates, The Ronald Press, 1961. According to F. Ling the development of design of bearing plates for columns is as follows:

Referring to Fig. (1).

For part I, the unit rotation about x-x axis

$$= \frac{1}{b\beta}$$

For part II, the unit rotation about the y-y axis

$$= \frac{1}{b}$$

D = internal dissipation of energy

D = (rotation) x (length of time) x (plastic moment)

$$D = \frac{1}{b\beta} \times 4\ b \times Mp + \frac{1}{b} \times 4b\beta Mp + \frac{1}{b} \times 2d \times Mp$$

$$= 4\ Mp\ \left(\frac{1}{\beta} + \beta + \frac{d}{2b}\right)$$

W = the external work

W = the volume of pyramids of deflection times the unit pressure.

$$W = \frac{1}{3}\ Fp \times bx\ b\beta \times 4 + \frac{1}{2}\ Fp \times b\ (d-2b\beta) \times 2$$

$$= Fp \times b^2\ \left(\frac{d}{b} - \frac{2}{3}\beta\right)$$

Let $\lambda = \frac{d}{b}$, set D=W

$$Mp = \frac{Fp \times b^2}{4} \times \frac{\lambda - 2/3\beta}{1/\beta + \beta + \lambda/2} \qquad \text{------------(4)}$$

There is only one value of β for which Fp is minimum or Mp is maximum.

Differentiating with respect to β and setting Mp' = 0, leads to:

$$-\frac{2}{3}\left(\frac{1}{\beta} + \beta + \lambda/2\right) + \left(\lambda - \frac{2}{3}\beta\right)\left(-\frac{1}{\beta^2} + 1\right) = 0 \text{ ---------(5)}$$

rearranging

$$\frac{\lambda - \frac{2}{3}\beta}{\frac{1}{\beta} + \beta + \lambda/2} = -\frac{2}{3} \times \frac{1}{1-\beta^2} = \frac{2\ \beta^2}{3(1-\beta^2)}$$

but from equation (4)

$$\frac{\lambda - \frac{2}{3}\beta}{\frac{1}{\beta} + \beta + \lambda/2} = \frac{4\ Mp}{Fp \times b^2}$$

therefore

$$\frac{2 \times \beta^2}{3(1-\beta^2)} = \frac{-4\ Mp}{Fp \times b^2}$$

$$Mp = \frac{Fp \times b^2}{2} \times \frac{\beta^2}{3\ (1-\beta^2)} \text{ ---------(6)}$$

At corners due to lack of full plastic moments Mp should be increased by 10 percent and also substituted for $Mp = \frac{Fy \times t^2}{4}$ and a factor of safety of 2 inserted

Thus $$\frac{Fy \times t^2}{4} = \frac{1.1\ Fp\ b^2}{2} \times \frac{\beta^2}{3\ (1-\beta^2)} \times 2$$

and $$t = 1.21 \times b \times \beta \times \sqrt{\frac{Fp}{Fy\ (1-\beta^2)}} \text{ -----------(7)}$$

To find the value of β, solve equation (5) by expanding and collecting: $-\frac{4}{3}\beta - \frac{4\lambda}{3} + \frac{\lambda}{\beta^2} = 0$

$$\beta^2 + \frac{\beta}{\lambda} = \frac{3}{4}$$

from which $$\beta = \sqrt{\frac{3}{4} + \frac{1}{4\lambda^2}} - \frac{1}{2}\lambda \text{ ----------(8)}$$

For example, compute the minimum thickness for a 14 x 8 WF column using Fp = 0.750 k.s.i. and Fy = 36 k.s.i.

where $\lambda = \frac{d}{b}$ see Fig. (1) $\lambda = \frac{12.62}{3.85} = 3.28$

using equation (8)

$$\beta = \sqrt{\frac{3}{4} + \frac{1}{4 \times (3.28)^2}} - \frac{1}{2 \times 3.28}$$

$$\lambda = 0.88 - 0.15 = 0.728$$

using equation (7)

$$t = 1.21 \times 3.85 \times 0.728 \sqrt{\frac{0.75}{3\,(1 - 0.728^2)}}$$

$$t = 0.711 \text{ inch}$$

Roark's equation for maximum deflection at middle of the free edge of a plate which is fixed on the opposite edge and supported on the other two edges can be restated

$$t = \sqrt[3]{\frac{1.37\ F_p \times b^4}{E_s \times a + \frac{10}{\lambda^3}}} \quad \text{----------(9)}$$

Assumption in the equation (9) is that plate a is nowhere stressed beyond the elastic limit.

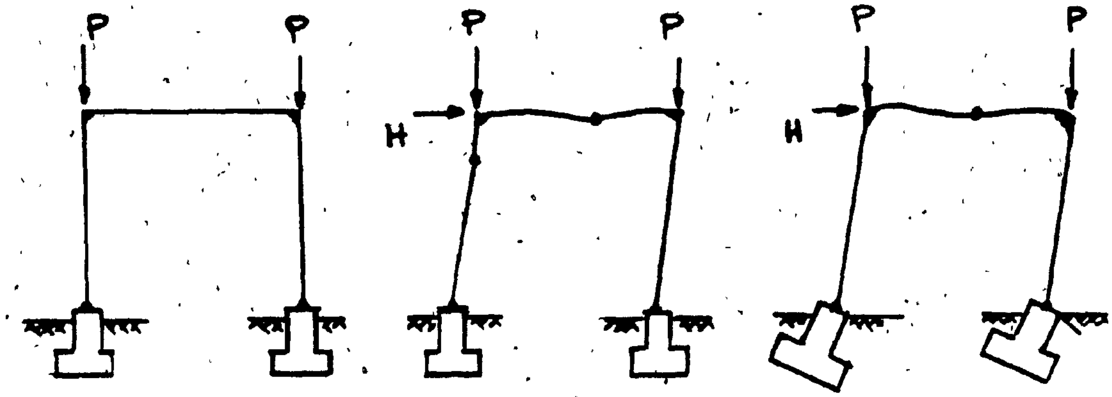
Another equation for finding thickness by Roark by setting maximum stress which occurs at the middle of the fixed edges, equal to the yield stress of the steel. Thus

$$t = \sqrt{\frac{3\ F_p \times b^2}{F_y\,(1 + \frac{3.2}{\lambda^3})}} \quad \text{----------(10)}$$

Note equation (10) merely gives minimum thickness for which equation (9) is applicable. Since the yield stress is used with no factor of safety equation (10) cannot be relied upon to give a plate thickness which will be sufficiently strong. The yield line must be used to check the ultimate strength.

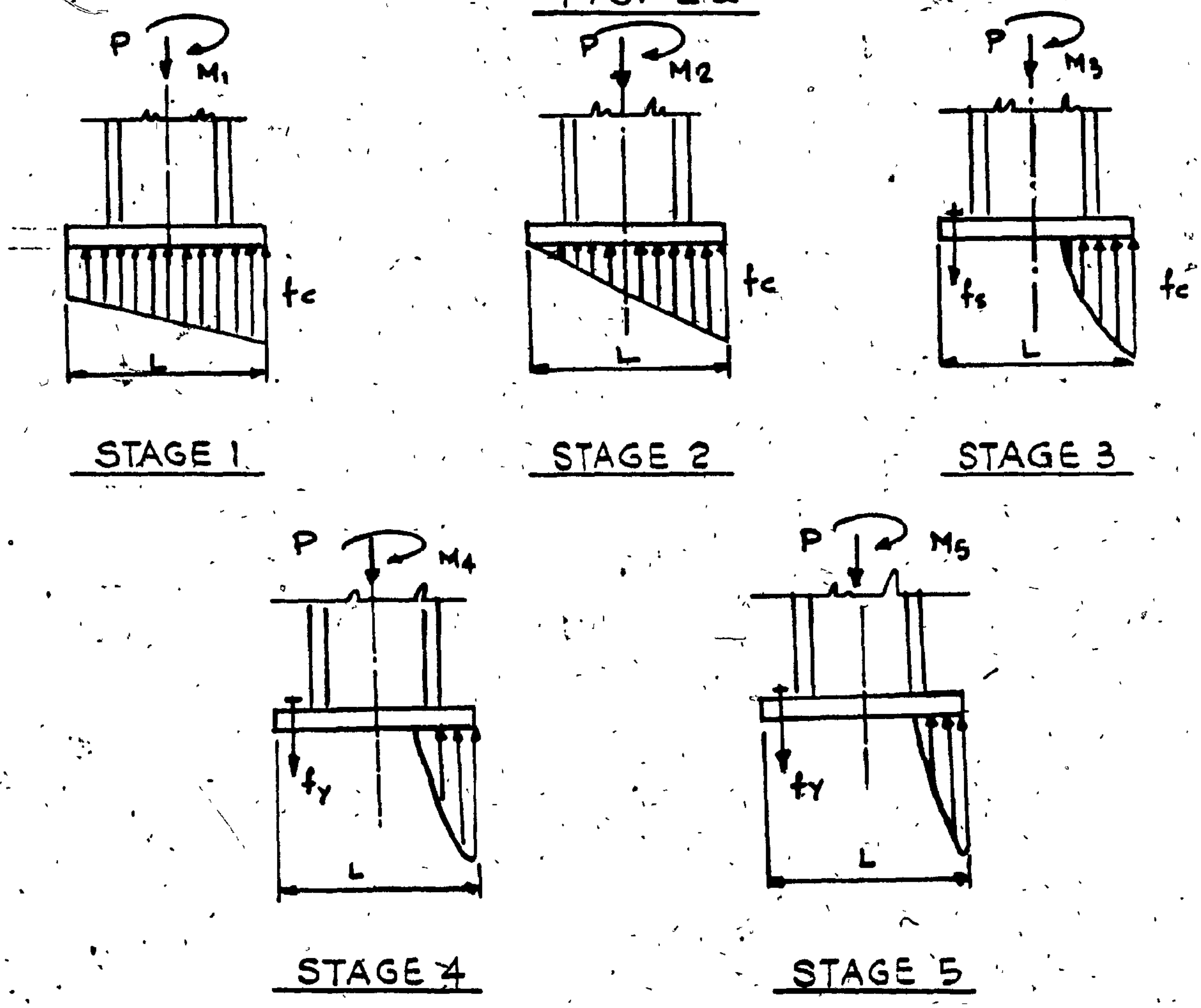
3.2 BASE ROTATION

The fundamental base rotation characteristic is an important factor to be discussed. Consider the frame of the building as shown in figure 2.0(a). Assume column bases are rigidly held to their concrete



FOUNDATION CONDITION

FIG. 2a



EFFECT OF VARYING MOMENT

FIG. 2b

footings and are axially loaded. If the soil underneath the footing is uniform, the stress distribution on the bottom of each footing will be symmetrical and therefore there will be no bending moment at the base of the column. If the lateral load is applied as shown in the Fig. 2(b) the frame will deflect. Should the foundation material be firm soil or rock and the footings are proportioned as not to strain the material significantly, each column base will be effectively fixed. If on the other hand the soil is compressible or size of the footing is inadequate the frame will deflect, regardless of the rigidity of the base connection, each column may behave as though pinned at its base.

Such conditions can also happen in case of heavy beam connected to very flexible column, despite the rigid connection, the moment at the end of the beam is insignificant. The rigid connection is pointless. Therefore it is important that a design engineer must determine the capability of developing rotational restraint.

It will be assumed that foundation has capacity to resist any moment transmitted to it without deforming significantly.

Beside the subsoil characteristic, the most important variables that determines the moment rotation for column anchorages are (a) dimensions of the base plate, (b) dimensions, location and stress strain characteristic of bolt, (c) vertical loading.

Five stages in response of a base to constant vertical load and increasing moment are shown in Fig. 2 (stages 1 to 5). The stage one holds for low values of moment the stress under the plate may be non-linear but assumption of linear pressure is acceptable. In stages 1 and 2 it makes no difference whether the anchor bolts are present or not. As long as there is full compression under the base plate, anchor bolts are not required. In such conditions bolts are provided for erection of steel. Once the moment is increased and tensile stress induced in bolt, this stage can go as far as most highly stressed bolt begin to yield as shown in Fig. 2.0 stage 3 and 4. Compressive stresses will be nonlinear Stage 4 encompasses the yield range of highly stressed anchor bolt and ends when they start strain hardening. Last stage 5 covers the case under which most highly stressed anchor bolt strain hardens and ultimately fractures. At this stage, crushing of concrete may occur or pulling out of anchor in tension.

The above stages can be classifed into three conditions.

(i) $\frac{e}{L}$ equal to or less than $\frac{1}{6}$ i.e., compression over the whole area of the plate where e is eccentricity of equivalent axial load and L is the length of the base plate.

(ii) when $\frac{e}{L}$ lies between $\frac{1}{6}$ and $\frac{1}{3}$

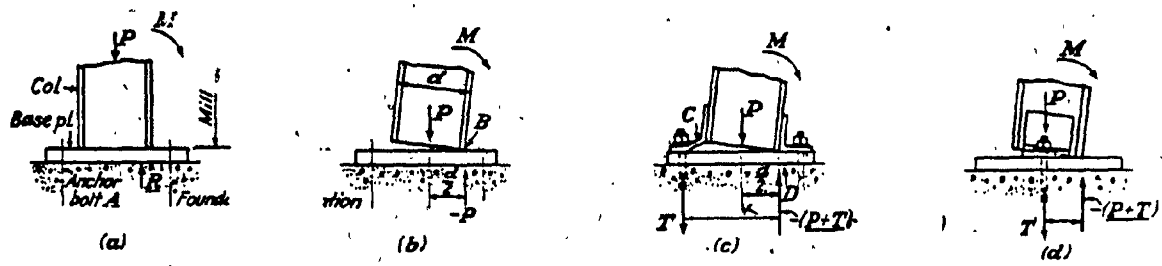
(iii) when $\frac{e}{L}$ greater than $\frac{1}{3}$.

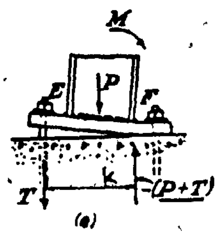
Conditions (ii) and (iii) are critical.

3.3 MOMENT ROTATION CHARACTERISTIC

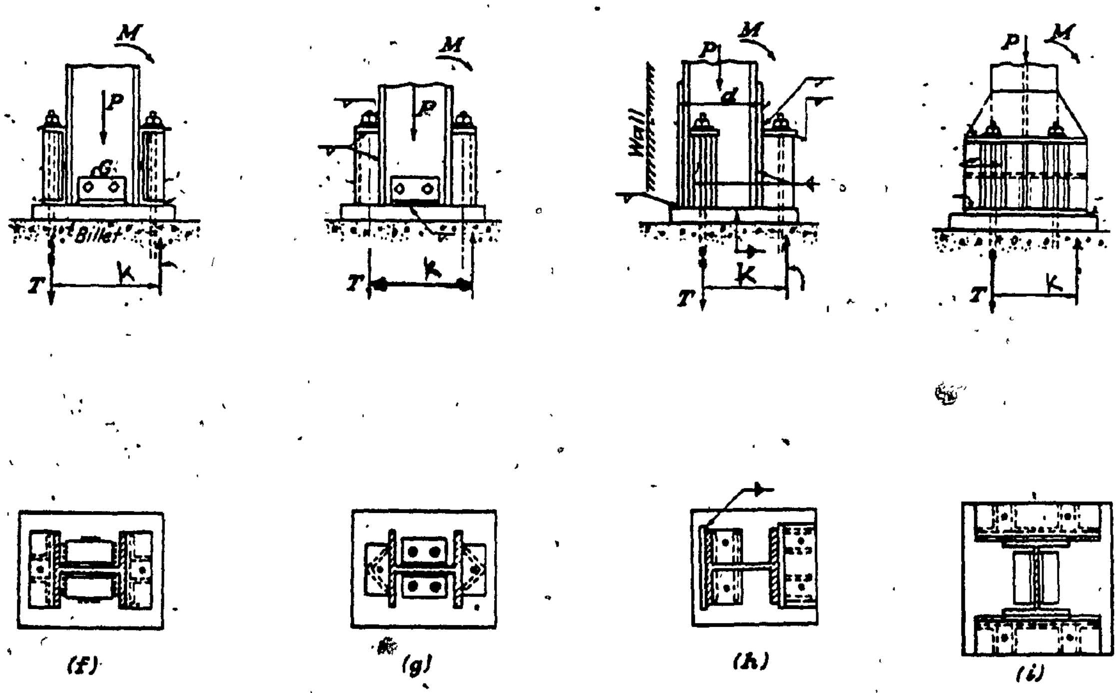
The methods of analysis or design for determining the moment rotation characteristics for common types of anchorages in light industrial buildings are useful for cases in which resistance to rotation may be critical to the survival of the structure under very heavy lateral loads such as blasts, earthquakes etc.

Anchorages of multistory buildings are unlikely to fail in shear because they are so rigid and friction due to axial load is so great





CONNECTIONS OF STEEL COLUMNS
TO CONCRETE FOUNDATIONS



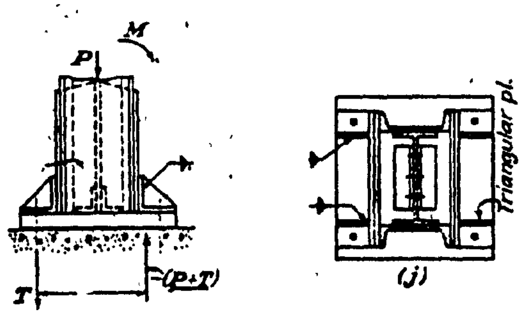


FIG. 3

In general the anchorages of tall buildings being heavily embedded in concrete, can be considered fully fixed, hence the deformation and failure would be governed by the properties of the columns. In most of the light industrial buildings, the column anchorages are between the two extreme cases of fixed and flexible anchorage. These consist of base plates attached to the bottom of the column and held down by anchor bolts embedded in a concrete pier or footing. Several papers have been published including paper by Charles Salmon, Schenker and Johnston which gives first approximation for designing moment rotation characteristic of base anchorage. Empirical procedures have been used for design purposes with the knowledge that a large factor of safety is available to absorb discrepancies between the assumptions and the actual behaviour of anchorages.

The total rotation of the column base is a function of rotation between the footings and soil, bending in the base plate, and the elongation of the anchor bolt. The derivation is out of scope of this paper, Refer to Metric Design Manual Precast and Prestressing Concrete of Canadian Prestress Concrete Institute, 1982 Chapter 4.

3.4 BASE CONNECTIONS

Some of the details shown in Fig. 3.0 (a to j) are frequently used in the day to day design and these can be further improved according to the conditions of a particular problem. It is customary to depend upon anchor bolts and base plate as the direct connection for resisting any tension caused by overturning. Columns may be embedded in the concrete but this is seldom effective in resisting bending stresses unless the embedment is 3 to 4 feet. (1 metre to 1.5 metres) deep and the concrete is designed to provide the necessary reactions.

(a) This shows a simplified condition and this might occur in case of a side wall column of a tall mill building in which the frame action of each bent (column and truss) is in one row across the building.

(b) A milled column shaft resting directly and squarely upon a base plate will offer some resistance to rotation because of the "riding" of the leward flange.

(c) Here base angles are connected to the column and the anchor bolts, the base plate being for the distribution of pressure only. Unless c see Fig. 3(c) is very stiff, it will bend as shown to an exaggerated scale, and it will yield excessively. It is obvious that these bolts must provide necessary downward reaction T and that the pressue P + T tends to be concerntrated near the leward flange.

(d) This shows the ineffectiveness of web angles on the column because both the short lever arms and the warping of the outstanding legs of angles. When the wind is 90° to the web of the column, these angles are also weak.

(e) This shows a base plate welded to column shaft. If the base plate is thick enough, it welds adequate and if the concrete can resist safely the arrangement may provide a greater lever arm and more effective resistance.

(f) This illustration shows one arrangement for "boots" at a column base to prevent weakness caused by the yielding of details.

(g) This is a minor modification of Fig. 2(f). All horizontal shear must be resisted by the web angles and the friction because the anchor bolts stand free of angles, see Fig. 3(g).

(h) Here the column is set so close to the face of the exterior wall that one pair of anchor bolts is placed inside of the outer flange.

(i) This shows a case where the wind is acting perpendicular to the column web.

(j) Here is a heavy column shown with channel cover plates and stiffening plates so that large movement can be resisted in any direction

3.4.1 CONNECTION BETWEEN BASE PLATE AND COLUMN

The column is attached to the base plate with clip angles or welded and should be properly designed so as to carry the load on the anchor bolt. The bolt tensions fixes the toe of the angle against the base plate and causes an inflection point between the bolt and the vertical leg of the angle, so that the bolt load is cantilevered only about half way. Use of bending theory, the thickness or size of angle shall be checked. The welds are treated as line load and section modulus of the weld and bending force is calculated.

3.5 PRECAST AND PRESTRESS COLUMN BASE

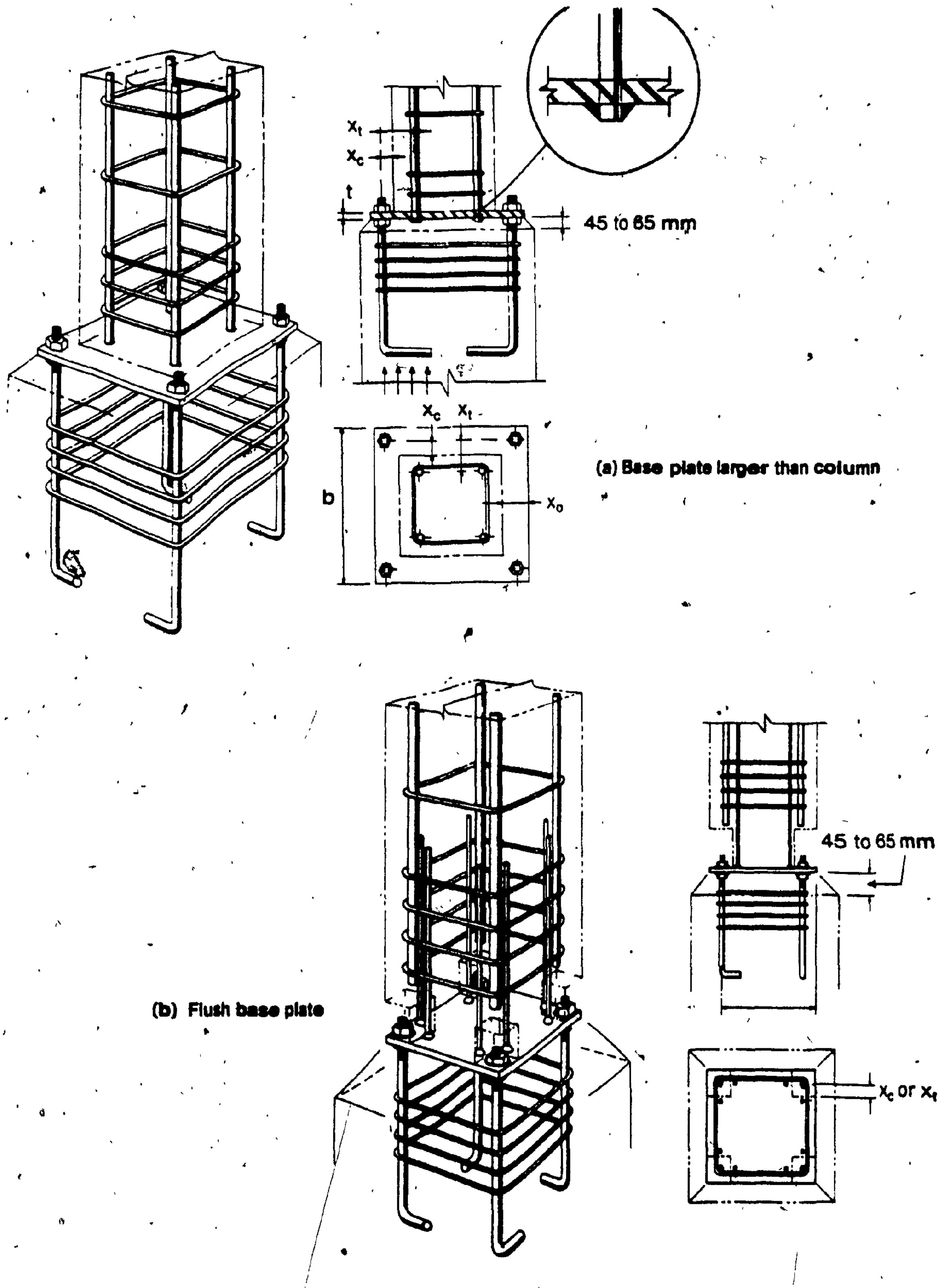
When the precast or prestress column base or base plate is provided to distribute the load on the pedestal, column bases must be designed for both erection loads and service loads. The thickness of base plate is calculated in the same way as in steel columns except for projection or cantilever of the plate shall be as follows:

(a) In case all anchor bolts are in compression projection x_t or x_c is from face of the concrete column to the center of anchor bolt or to the edge of the plate.

(b) If the anchor bolts are in tension one or both sides projection x_t or x_c is center of main reinforcement of column to the center of bolt or edge of the plate.

When the bolts are near a free edge as in a pier wall, the buckling of the bolts before grouting may be a consideration. Confinement reinforcement as shown in Fig. 4.0 should be provided, a minimum 4-10 M ties at about 75 mm is recommended for confinement. The design of anchorage is described in the following chapters. Bearing area of the bolt heads can be increased by welding a washer or steel plate to the bolt head.

Compression on anchor bolts during erection can be reduced substantially by the use of steel shims.



PRECAST AND PRESTRESS COLUMN CONNECTIONS

FIG. 4

CHAPTER – 4

ANCHOR BOLTS

Chapter - 4

ANCHOR BOLTS

4.1 ANCHORAGE

Experience has shown that the most critical points of structures are connections and anchorage is one of them. As a result of increased use of high strength materials, thus higher stresses per meter square must be transferred between the structural element than ever before. It is at these points that stresses are concentrated and the greatest care in design, detailing and construction is required. Anchorage systems are required to connect the various equipment, vibratory machines and others to concrete foundations.

An anchorage system or connection by an anchor bolt or expansion bolt or insert and grouted bolt must be reliable, economical and simple. Each anchorage should be of adequate strength to perform for which it has been designed.

It must be capable of required quality installation under field conditions and be able to perform well throughout the life of the structure.

Based on experience and extensive laboratory tests of structural members, factors of safety have been reduced but at the same time, degree of knowledge and security should be applied to the connection design and construction. The anchorage system can be classified into four types:

a) Embedded Anchor Bolts

b) Expansion Anchors

c) Grouted Anchors

d) Inserts or Concrete Inserts

A brief explanation of the above four types of anchor bolts is given below.

a) ANCHOR BOLTS

Most industrial structures depend on concrete foundation for support and stability with particular reference to stresses of shear, tension and compression. Anchor bolts are most commonly used and perhaps the simplest form of anchorage. Anchor bolts are of many types and usages, ranging from the 1/2" (12 mm) and smaller bolts for anchoring light machinery and the structures to the 50 mm and 75 mm diameter bolts for anchoring arches, bridges and other heavy structure. Anchor bolts of various grades of steel, alloys are manufactured meeting most of design requirements. Anchor bolts having high strength and improved charpy v-notch impact properties. For convenience of specifying Stelco manufactures anchor bolts using class designations. Five classes have been selected to cover most design conditions and also limited to those steels readily available.

CLASS -1 Conventional Reinforcing Steel

These are produced in accordance to CSA standard G30.12-M. The specification covers deformed bars for concrete reinforcement with two minimum yield strengths 350 MPa and 400 MPa.

CLASS -2 Stelweld 400 Reinforcing Steel

This is produced in accordance to CSA standard G30.16-M in single minimum yield point 400 MPa. This material offers superior weldability and ductility over the equivalent strength Grade Class -1 anchor bolt.

CLASS -3 High Standard Steel

Anchor bolts of this class are medium carbon steel produced as quench and tempered smooth bars. The quality of this steel is similar to ASTM A325 structural bolts and this steel can be listed to charpy v-notch impact values if requested.

CLASS -4 High Strength Alloy Steel

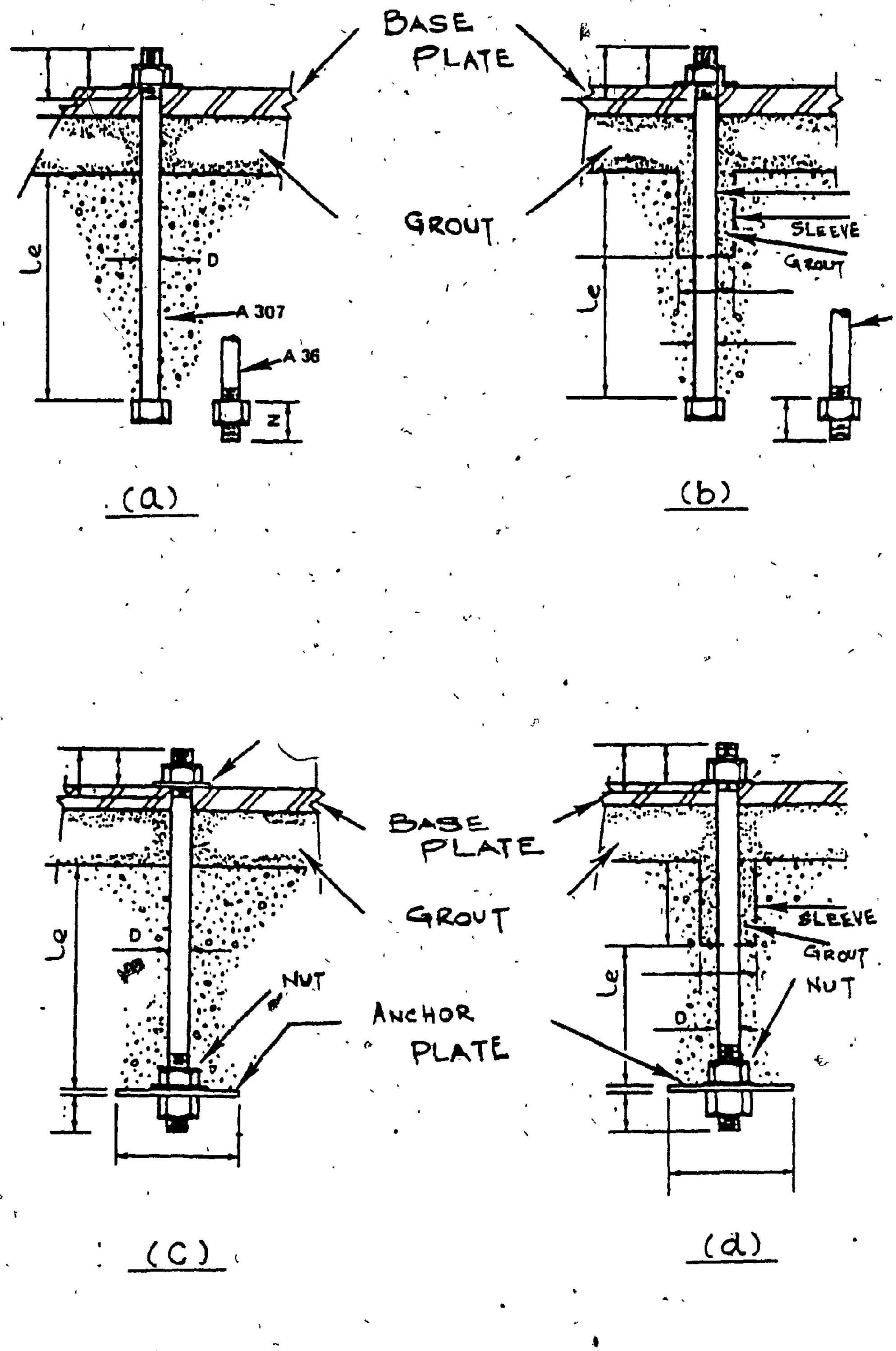
This is an alloy steel produced as quench and tempered smooth bars, having higher strengths.

CLASS -5 ASTM A687

This is an alloy steel, produced as quench and tempered smooth bars with mandatory charpy v-notch impact properties.

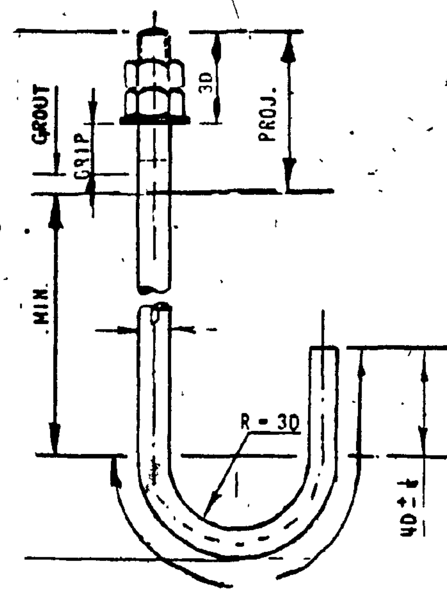
Class - 1 anchor bolts have been used for general anchorage in construction industry. For greater concern anchor bolts Class -2 are specified. Class -1 and Class -2 are also available in deformed bars. Class -3, -4, -5 anchor bolts are quench and tempered high strength steels used in special conditions of high tensile forces, for exposed structures, impact loading, extreme cold and hot temperatures. Before using the anchor bolts for special conditions specifications shall be checked and verified with the manufacturer. Standard nuts and washers should match the properties of the anchor bolts. The various shapes of anchor bolts are shown in Fig. 5, Fig. 6 and are commonly used in the industry.

The original form of anchor bolt or rag bolt (Lewis Bolt) with rugged protrusions is for better grip in concrete. These have bean largely replaced by the modern indented foundation bolt. Hydraulically stretched

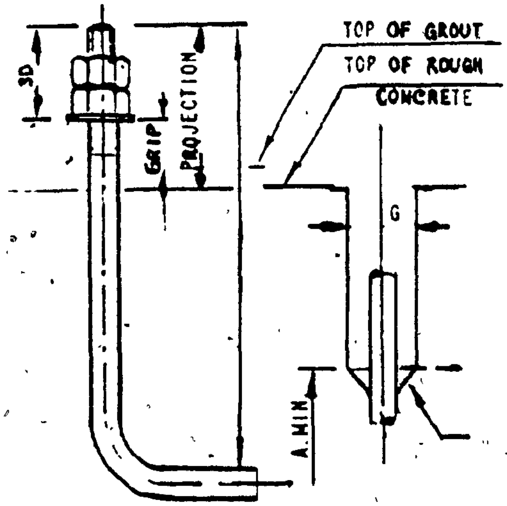


TYPES OF ANCHOR BOLTS

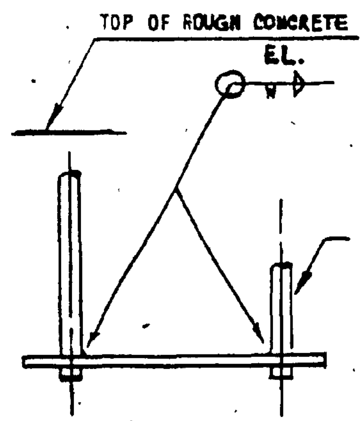
FIG. 5



ANCHOR BOLT (HOOKED)



ANCHOR BOLT (BENT)



ANCHOR BOLT
(COMBINED)

TYPE OF ANCHOR BOLTS

FIG. 6

bolts, wedge type with shank split, toggle bolts, screw plugs, nail anchors are varieties of small fasteners.

b) EXPANSION BOLTS

Such anchors are normally based on an expansion principle whereby tightening the bolt expands the anchor body or a section of the body to grip the sides of the hole into which it is fitted to transfer loads into structural component by direct bearing and or friction.

Caulking anchors are available in three types:

a) Machine screw anchors

b) Machine bolt compound anchors (multiple unit)

c) Stud bolt anchors (single unit), see Fig. 7

Caulking anchors consist of lead sleeves and a threaded zinc, brass, or malleable expander, comprising a single unit. These anchors are accomplished by expanding (caulking) lead sleeves over the expander element in a hole predrilled to the manufacturer's specifications. Caulking is done by hammering with a caulking tool. These anchors develop high power of load resistance in relation to the hole depth requirements.

Mechanically expanded anchors are also available in five classes: a) single cone b) double cone c) closed back d) four legged closed end and e) stud bolt. The anchors are dropped or tapped (with light hammer) into predrilled holes. After the fixture is positioned, a machine bolt is inserted through the fixture and threaded into the expander.

Stud bolt types are dropped into predrilled holes after the fixture is positioned. The tappered end of the bolt is drawn into the shell by tightening a nut on the bolt. These bolts can hold up to 11,000 lbs. (49 KN).

Long shield expansive anchors.

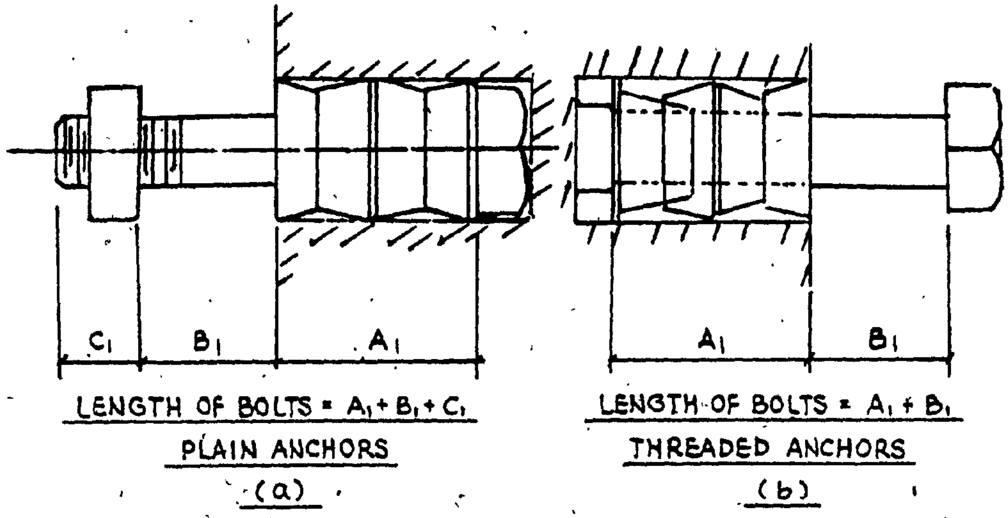
These consist of a shell having an internal thread that conforms with the configuration of a lag screw. They are manufactured from zinc alloy or in special sizes from malleable iron. It is a simple matter of dropping (or tapping) the shell into the hole drilled to the manufacturer's specifications, then placing the fixture in position, a lag screw is inserted into the shell and tightened. Maximum expansion is acquired by completely threading the lag screw into the shell.

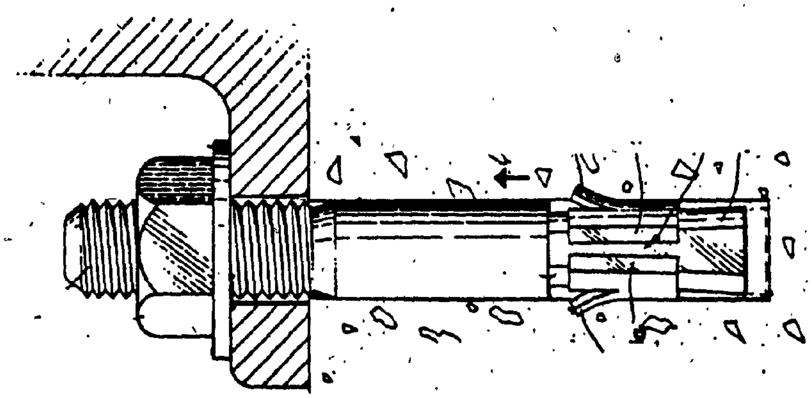
Manually expanded anchors consist of self drilling anchors, steel shell drop-ins solid steel stud anchors see Fig. 7.0. Self drills are comprised of a steel shell, having cutting teeth at the lower end and a steel expander plug over which the shell is expanded. Steel shell drop-ins are similar to self drills, except the shell has no cutting teeth. Self drilling are available in two head styles: a) tappered heads b) flush heads. All of these are core drills.

The tappered heads are inserted in elastic or air hammer chucks and will drill their own holes by manually swivelling the chuck while employing the hammering action of the power hammer. Tappered head types are expanded by hammer action of the power hammers (without rotation). Expansion anchors shall not be used to resist vibratory loads in tension zone.

c) GROUTED ANCHORS

In this case a stud or bolt fitted in an oversize hole partially filled with grout. The bolts are then suspended so that they are centered in the holes. The bolts are wiggled and moved in and out of





(c)

EXPANSION BOLTS

FIG. 7

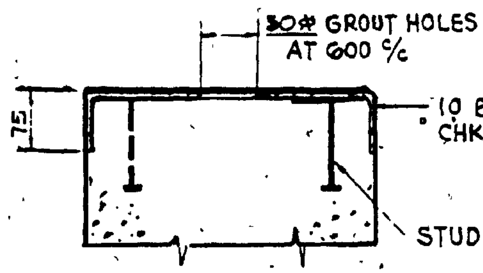
the holes to rid of the grout paste of any voids. The bolts are secured so that they extend into the holes of required depth where the initial grout get hydrated, the remaining portion of the holes are then filled with more grout paste. When the grout reaches sufficient strength, the plates are fastened to the bolts by tightening the nuts to "snug tight".

Grouts are used frequently for their special characteristics. Special grout shall be tested to verify their required properties. The usual grout, one portland cement and three parts fine sand by volume mixed with water or one part of portland and three parts of fine sand by volume. In lieu of water, a singular dispersion of polymer resine can be used as liquid or premixed nonshrink grout.

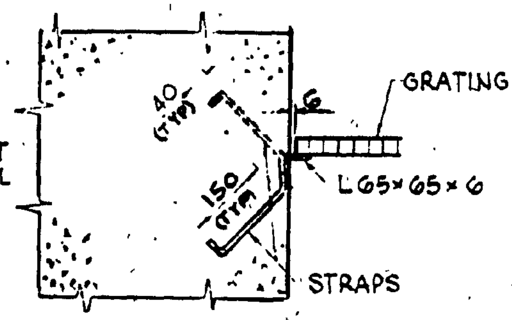
d) CONCRETE INSERTS

These are predesigned and prefabricated embedments and usually installed prior to the placement of concrete. These are commercially available and specially designed for attachment of bolted connection. The embedment and surrounding concrete shall be designed for transmitting to the concrete structure all loads used in the design of the attachment. The strengths of embedment is effected by size grade of steel, spacing and depth of embedment and dimensions of concrete.

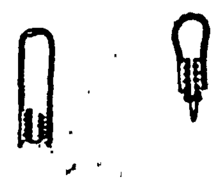
Inserts may be classified into four categories: a) light b) medium c) heavy duty and custom fabricated. Light inserts are used in thin slabs, flat slabs to support false ceilings, water lines etc., see Fig. 8.0.



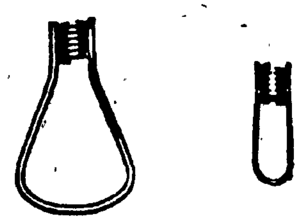
EMBEDDED DOOR SILL



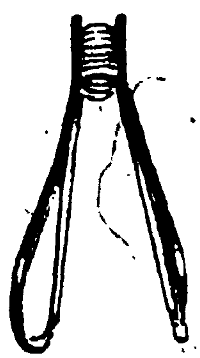
GRATING PLATE COVER SUPPORT



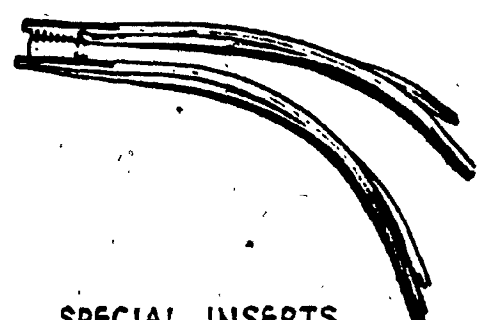
LIGHT DUTY INSERTS



MEDIUM DUTY INSERTS



HEAVY DUTY INSERTS



SPECIAL INSERTS

INSERTS

FIG. 8

Safe load carrying capacity in tensions vary with the insert bolt diameter and are usually 1000 N (200 lbs.) for 3/8" diameter (10 mm) diameter up to several thousand of pounds (Newtons) for 25 mm or inch diameter inserts.

Medium duty are used in anchorage of forms to previous cast-in places concrete. Handling of precast units is done by inserts anchorage see Fig. 8.

Ultimate capacity for inserts of this type vary from 2000 lbs. (9 KN) to 18000 lbs. (80 KN).

Heavy duty inserts are used for anchorage of steel cantilever lock and dam construction. It is also used for handling heavy precast units as shown in Fig. 7. Ultimate capacities of such types of inserts range from (80 KN to 355 KN) 18000 lbs. to 80000 lbs.

Special anchors or inserts are fabricated to suit unusual conditions due to reinforcing steel or prestress locations in a concrete member. Such inserts are generally fabricated of wire weldment configuration.

CHAPTER - 5

DESIGN OF ANCHORAGES

Chapter - 5

DESIGN OF ANCHORAGES

5.1 MOMENT RESISTANT ANCHORS

A moment resistant anchorage is desirable at the base of the columns and this is done in light industrial buildings producing light column and reducing the lateral deflection.

When the ratio of moment to axial load is such that $\frac{e}{L}$ where e is the eccentricity and L is the length of base plate lies between 1/6 or 1/3 and greater than 1/3 (Tension over an area of 1/3 or less and tension over an area more than one third), anchor bolts are essential to maintain the equilibrium. See Fig. 2 (stage 3, 4 and 5).

In normal working stress condition, combined theory, the stress in concrete

$$f_c = \frac{P}{A} \pm \frac{M}{S}$$

$$f_c = \frac{P}{B \times L}\left(1 \pm \frac{6e}{L}\right) \qquad \text{------------(11)}$$

when the enccentricity is sufficiently large in proportion to the direct load to make $\frac{M}{S}$ factor of the equation greater than $\frac{P}{A}$ factor equation 11 no longer holds true and a vigorous analysis leads to a cubic equation.

Therefore, to find the maximum tension in the bolt and maximum allowable bearing pressure on concrete following methods are commonly used.

5.2 PRESENT METHOD

5.2.1 WORKING STRESS

When the moment is small compared to axial load, designing of base plate or anchor bolts is simple, use equation 11. In cases where moment is quite large compared to axial loads, see Fig. 9.0, it may be noted that three vertical forces, PCT. The first preliminary equation is found by equating their summation to zero

$$P + T - C = 0 \quad (12)$$

Thus there are three unknowns requiring at least three equations and second of this found by setting the summation of moments about the force C equal to Zero.

Referring to any standard text book e.g., Gaylord and Gaylord and John E. Lothers "Design in structural steel," standard values are calculated in form of equations.

The method is based on concrete beam analogy method, such that center of compression is at the centroid of triangular prism, see Fig. 9.0 at the top of the analogous concrete beam. In a similar manner, the resultant axial load that "e" inches out from the center line of the column must pass through the centroid of the stress prism in the concrete footing beneath the base plate: .The following equations are reproduced for calculations.

$$P\left(\frac{x}{3} \pm \Omega\right) - T\left(a - \frac{x}{3}\right) = 0 \quad \text{----------(13)}$$

Plus sign will apply when equivalent load line falls outside the leeward edge of base plate and minus sign will be used when it falls within the base plate

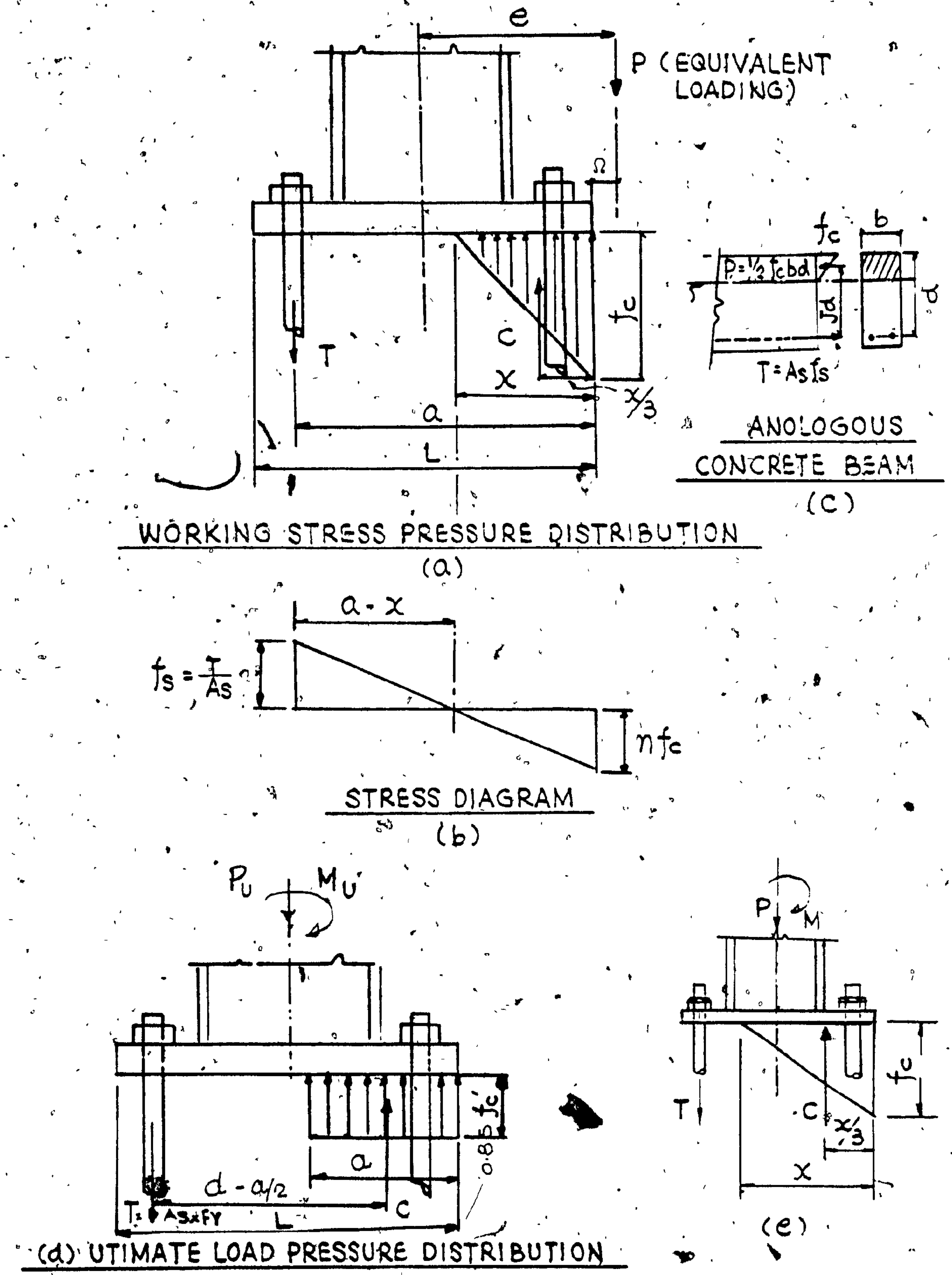
$$\frac{nfc}{T/AS} = \frac{x}{a-x} \quad \text{----------(14)}$$

Equation 14 gives a transformed section by similar traingles, see Fig. 9.0 in which AS is the total cross sectional area of the windward anchor bolts and "n" is modulus of elasticity ratio of steel to concrete.

Finding expression for P and C

$$P = \frac{T(3a - x)}{x \pm 3\Omega} \quad \text{----------(15)}$$

Since C is numerically equal to the volume of the compressive stress prism.



COLUMN BASE PLATE PRESSURE DISTRIBUTION

FIG. 9

$$c = \frac{B \times X \times f_c}{2} \qquad \text{------------(16)}$$

Equation in terms of x

$$x^3 \pm 3\Omega\ x^2 + 6nA_s\ \frac{(a \pm \Omega)}{B}\ x = \frac{6nA_s\ (a \pm \Omega)}{B}\ a \qquad \text{---------(17)}$$

To make the analogy perfect, however, the moment arm by which the bolts are analyzed for tension would have to be (a−x/3) see Fig. 9.0, the latter corresponds to jd of the analogous beam. Futhermore, the area required of the anchor bolts would have to be inversely proportional to the length of the moment arm. On the contrary, their area is directly proportional to (a−x/3). Therefore, so far as anchor bolt analysis is concerned, the analogy fails. Thus in case $\frac{1}{6} < \frac{e}{L} < \frac{1}{3}$ the computable stress for windaward anchor bolt is small. The above beam theory is applicable only for large moments and small axial load i.e., $\frac{e}{L} > \frac{1}{3}$

5.2.2 ULTIMATE METHOD

The method is based on assuming that the anchor bolt is yielding and the nonlinear concrete bearing stress distribution at failure can be represented by stress block, see Fig. 9.0 (d). It is generally assumed 0.85 fc' which corresponds to the basic value used in reinforced concrete beam design.

Therefore equilibrium of vertical forces

$$P_u = 0.85 \times fc' \times a \times B - A_s \times f_y \qquad \text{-----------(18)}$$

Taking moment about the resultant compession

$$M_u - P_u \frac{(L - a)}{2} = A_s \times f_y \left(d - \frac{a}{2}\right) \qquad \text{------------(19)}$$

5.3 COMMENTS ON PRESENT METHODS

The working stress method which is based on concrete beam theory is approximate. In reinforced concrete beam design, assumes a homogenous, continuous section following the beam theory i.e., plane sections remaining plane. In practice the discontinuity occurs at the base plate.

a) The change from embedded bolt to free bolt.

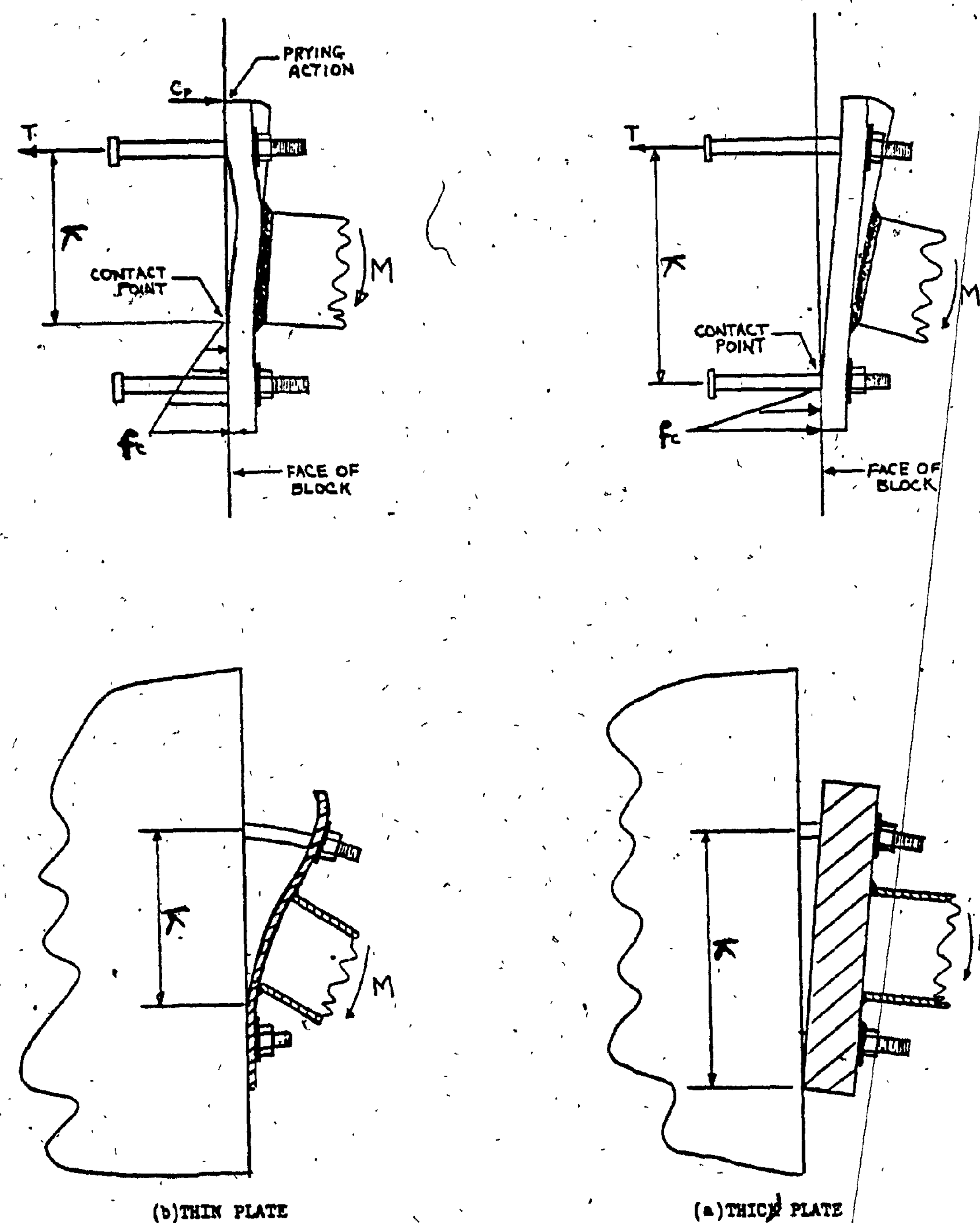
b) The change from concrete in bending compression to a smaller area in bearing compression.

c) Some loads due to initial tension in bolt and levelling nuts, shimming. Therefore stresses in concrete at some distance from the base plate may be true, are not essentially true at the base plate.

The important factor is the location of centroid of the compression area depends upon the relative stiffness of the plate and its assembly parts. According to one of research reports on Moment resistant concrete anchorages by Machony and Burdette, The University of Tennessee, see Fig. 10.0 shows that top of windward anchor bolts are always in tension and bottom anchors are slightly stressed provided the base plate is flexible. The force in top anchors was approximated by assuming a distance say K between the anchors and the compressive force C where K was taken as the distance from the top anchors to the point at which the concrete surface and the plate made first contact see Fig. 10.0. Therefore tensile force in the top anchors could be calculated.

$$T = \frac{P \times e}{2 \times K}$$ where 2 is constant

from the fact that there are two bolts in tension. It is noted by the formula that a greater value of K would decrease the stress in the top



APPROXIMATE BASE PLATE DEFORMATIONS

FIG. 10

anchor bolts but there are two major parameters which effect the value of K, the plate thickness and the magnitude of the load. A thick plate would not bend readily, the whole anchorage would tend to rotate about the bottom edge of the base plate, see Fig. 10. If a thin plate were used, the bending resistance would be very small and plate would tend to rotate about a point very near the bottom edge of the column section. As the increase in load would cause the plate to rotate more, therefore contact point between the plate and the concrete would move downward increasing value of K, resulting increase in moment capacity of the anchorage. The other way of increasing the anchorage stiffness is by prestressing the anchors by tightening the nuts to a known level. Since the columns are welded to the base plate, the part of prestress will be lost due to plate bowing induced by welding.

It was found that by varying the plate thickness would directly vary anchorage stiffness. Furthermore plate thickness should not be overmatched with anchors. Since the location of the centroid of the compression area of concrete depend upon the relative stiffness of the components of the base plate assembly, a thin unstiffened plate may move the resultant compression close to the face of the column flange whereas the thick plate moves the rotation to the edge of the plate.

Basically we know the location of eccentric applied load P at an equivalent distance "e". The upward compression on concrete whose magnitude and location is unknown and usually assumed or calculated by beam analogy method. The tension force in the bolt is unknown whereas the location of the bolts is known. By using some method location of compression is found and then the tension in the anchor bolts.

By studying all these behaviours of plate and assembly parts a rapid solution can be obtained without the use of cubic equation or charts and other complex methods.

5.3.1 PROPOSED SOLUTION (APPROXIMATE)

First of all, judgement should be applied in selection of base plate thickness, stiffness initial tension, double nuts, grouting, shimming and washers. A reasonable thickness of plate shall be selected. Assume center to center distance between the bolts and calculate approximate tension bolt including some effect of axial load, so that the length of the plate can be fixed. Assume one third or less of length of plate as distance "x" for triangular pressure. Assume the allowable bearing stress, calculate the width of plate "B", summation of vertical forces equal to zero.

Calculate thickness of plate see Chapter 6.0 solved examples by this method. Thus a reasonable assumption for the location may be made without little effect on the anchor bolt tension unless the plate is very small.

Working stress method gives a reasonable factor of safety in the vicinity of 2.0. Therefore working stress is appropriate since low stresses produce low moment-rotation.

5.3.2 Similarly in ultimate strengths method bolt is yielding and that the nonlinear bearing stress distribution at failure can be replaced by an equivalent rectangular stress block. This, however, neglects the favorable influence of confinement which exists in the base plates positioned on concrete foundation of greater area.

According to Dewolf and Sarisley prefer the ultimate method since it more closely models the actual behaviour and since it reflects the trend today towards limit design.

5.3.3 Another approach is to assume the traingular pressure distribution of bearing forces, see Fig. 9(e) however, the center of gravity of the triangle or concentrated force representing the triangle is assumed to be fixed at the point coinciding with concentrated compressing force of the column flange. From the assumption, the overhang of the bearing plate i.e., distance from the column flange to the plate's outer edge is seen to equal 1/3 of the effective bearing length.

5.4 ANCHORAGE REQUIREMENTS

5.4.1 EMBEDMENT

Embedment is, in fact the key to anchorage design. The factors which can affect the ultimate strength of the anchor bolt are embedment length, the development of full or partial cone (shear) which depends on anchor spacing, boundary conditions, concrete shear strength, and shear friction. Anchorage system shall be designed such that its capacity shall not exceed that of the embedded part and further concrete capacity surrounding the anchorage itself shall not exceed that of the embedded part.

A full shear cone is assumed to exist if the adjacent anchor center lines are at least a distance of (2Le + dh) from the center line of the anchor shear cone or if not edge boundaries are closer to the cone than $(L_e + \frac{dh}{2})$ where L_e is the embedment length and dh is the head diameter of the anchor. If the loaded bolts are closer than twice embedment depth than the overlapping area of the radiating stress cones also loses area which should be compensated for by increasing embedment depth to assure full tensile strengths development. The peripheral shear as described in the building code is same as the net resisting tensile stress area prescribed by a 45° degree line radiating from the edges of the loaded area to the bottom surface of the slab or footing. Breen found that bolts without end anchorage develop the capacity in bond through friction and adherence before pulling out. The inclusion of the end anchorage completely changes the load capacity, although at the expense of much slips. Breen suggested for A_7 (33 k.s.i. yield) can be fully developed with a 15 diameter embedment length and a standard nut anchor in all bolt sizes.

Anchor bolts that are not quenched and tempered and one inch or less in diameter may be hooked to increase their pullout resistance. P.C.I. research shows that hooked anchor bolts fail by straightening and pulling out of the concrete. This failure is precipitated by a localized bearing failure on the hook.

5.4.2 TENSION

Embedment can be assured by equating the tensile strength of anchors to the pullout cone strength of the concrete using a uniform tensile strength of $4\,\phi\,\sqrt{fc'}$ acting on a projected area confined within limits of intersecting cones radiating from the heads of the bolt at the base of the anchorage.

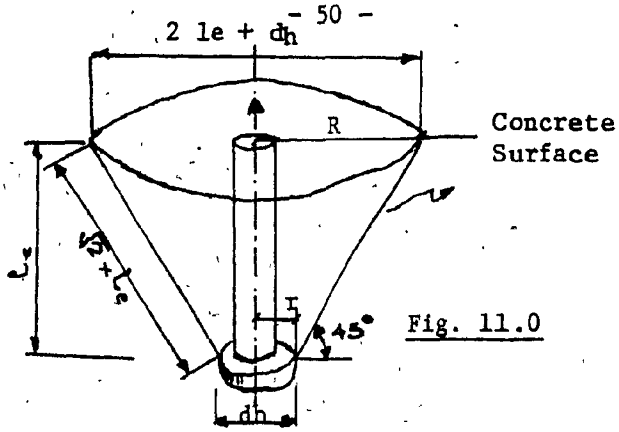


Fig. 11.0

FULL CONCRETE SHEAR-CONE

Figure 11.0 shows headed anchors or threaded rods with nuts and washers fail by a concrete mode. The effective area shall be limited by overlapping stress cones, by the intersection of the cones with concrete surface, by the bearing area of anchor heads and by overall thickness of concrete, see Fig. 12 and 13. Using ACI (349-78), ϕ factor shall be taken as 0.65 for an embedded anchor head unless anchor head is beyond the far face of reinforcement in such case, 0.85 may be used.

Tensile strength in concrete (full cone)

$P_{uc}' = 4 \phi \sqrt{fc'} \times A_o \times C$ -----------(20)

A_o = Surface area or $\pi S_1 (R + r)$ or $2 \times l_e \times (l_e + d_h)$

C = Constant for concrete type

For normal wt C = 1.0

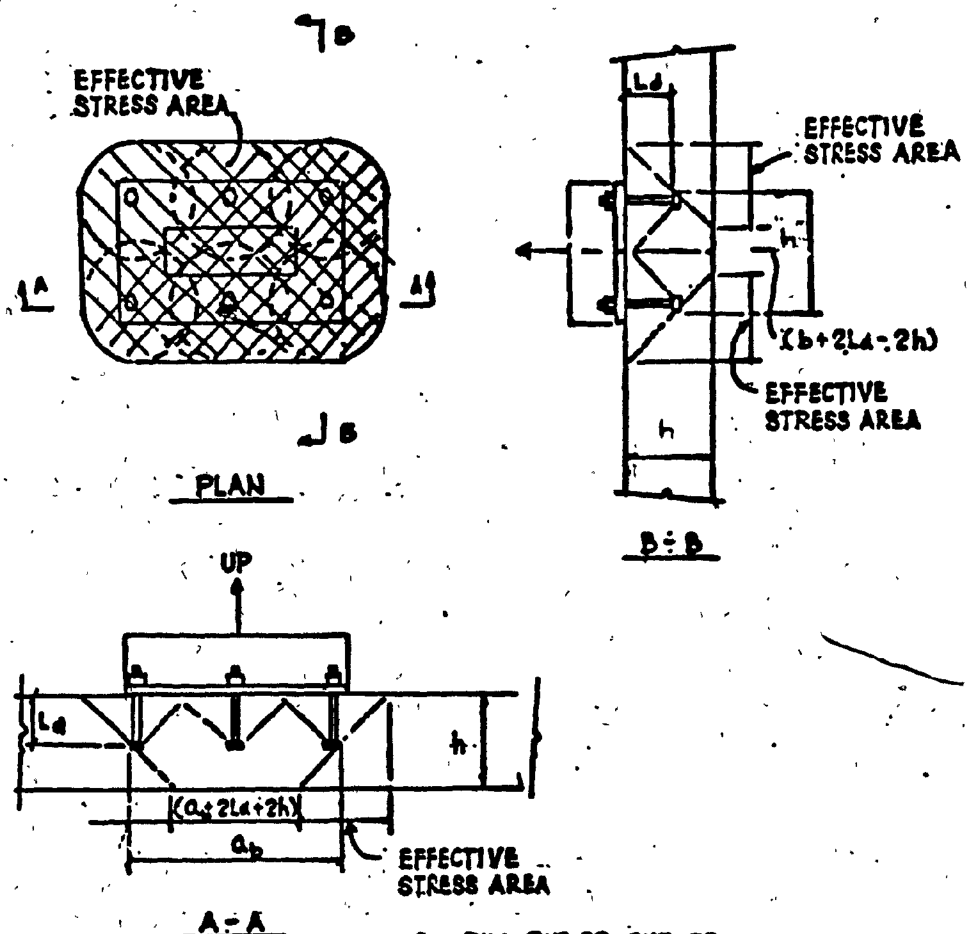
Light wt concrete C = 0.75

Sand light wt concrete C = 0.85

The expression may be restated as in Leigh's report

$P_{uc}' = 0.475C (L_e + d_h) \sqrt{fc'}$ in kips

P_{uc}' = Ultimate full concrete shear cone strength per bolt

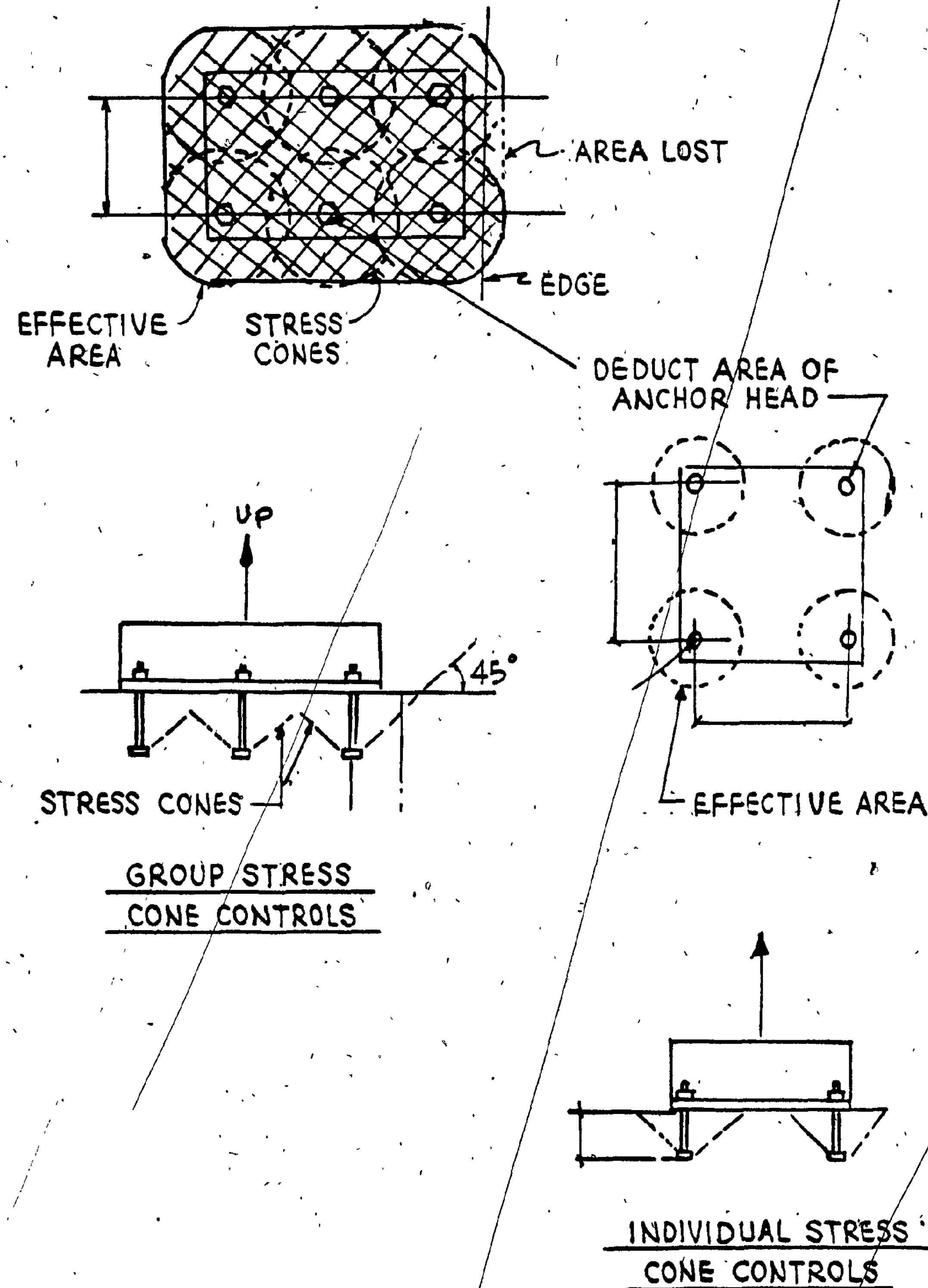


a_b: DIM OUT TO OUT OF BEARING EDGES.
h: OVERALL THICKNESS OF CONCRETE
b: DIM OUT TO OUT OF BEARING EDGES.

STRESS AREA REDUCTION FOR LIMITED DEPTH (A_r)

$$A_r = (a_b + 2Ld + 2h)(b + 2Ld - 2h)$$

FIG. 12



OVERLAPPING OF SHEAR CONE AREAS

FIG. 13

5.4.2.1 LOAD TRANSFER

Load transfer from steel to concrete shall be accomplished by one of the following:

(a) Minimum gross area of anchor head (including area of the tensile stress component) equal to at least 2.5 times the tensile stress area of this tensile member of anchorage. To prevent failure due to lateral bursting forces at an anchor head, the side cover distance "m" shall not be less than

$$m = D \sqrt{\frac{f_{ut}}{56\sqrt{fc'}}} \qquad \text{-------------(21)}$$

where

D = the nominal diameter of the threaded anchor.

f_{ut} = the minimum specified tensile strength

(b) Deformed reinforcing bars in accordance CSA with requirements of Clause 9.1

5.4.2.2 TENSILE CAPACITY OF STEEL

The required strength Pus' for embedments shall be based on a maximum steel stress of ϕ fy

ϕ = 0.9

fy = minimum yield point of steel

$$Pus' = \phi \times fy \times A_s \qquad \text{-----------(22)}$$

A_s = Tensile stress area of bolt

Pus' = Ultimate tensile capacity of bolt

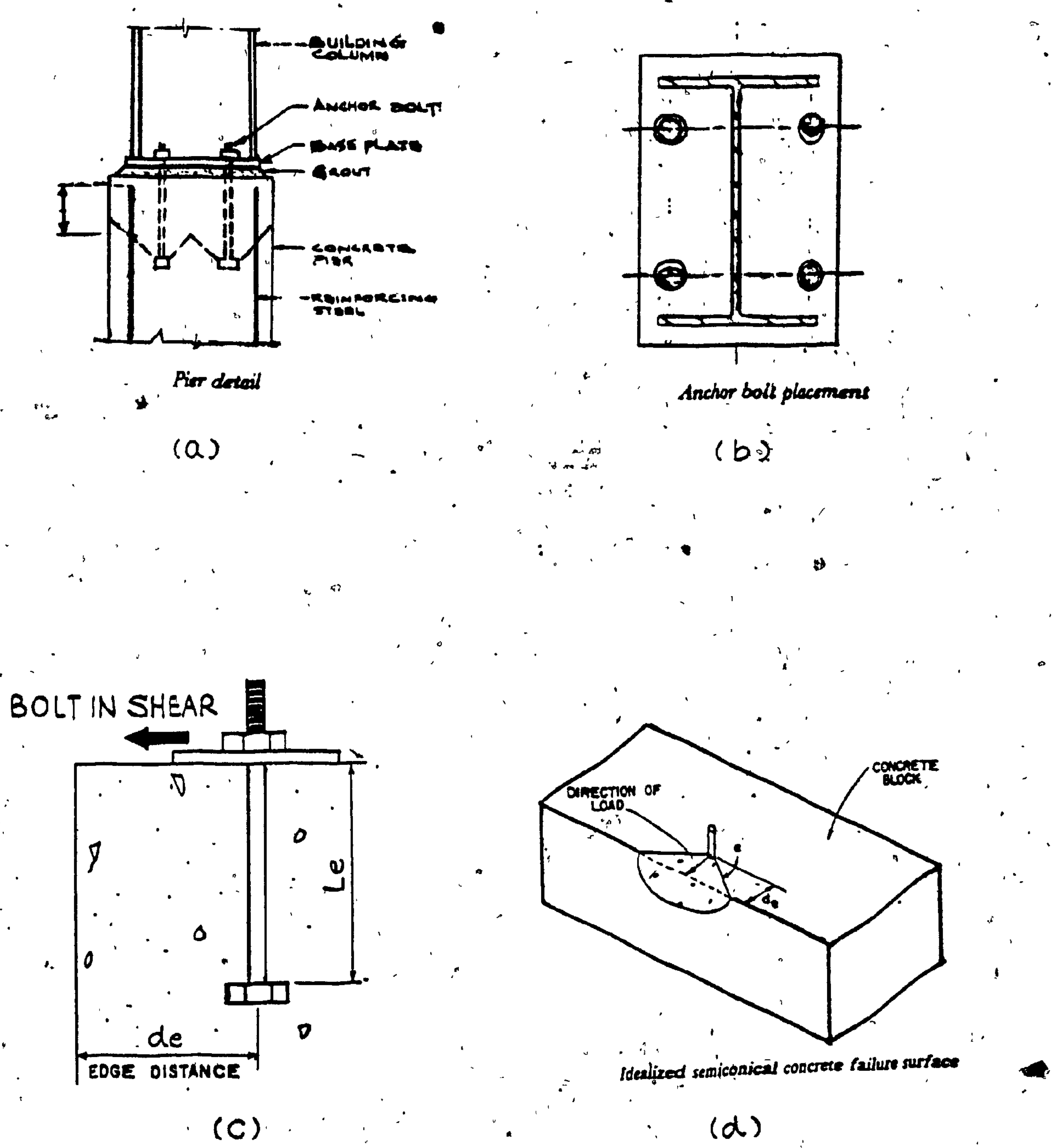
5.4.2.3 DEVELOPMENT OF REINFORCING BARS

In addition to making sure that the anchor bolt is sufficiently anchored in the concrete, the steel reinforcing in the foundation system must be positioned and detailed to provide suitable development length, see Fig. 14 (a).

The reinforcing must be developed in accordance CSA or ACI (318-77) requirements. If the reinforcing bar is not positioned against the anchor bolt then the development lengths L_d should be measured from the intersection of the bar and assumed conical failure surface. The capacities of anchor bolt (tensile) can be obtained from A.I.S.C. allowable stresses Table 1.5.2.1 of A.I.S.C. Manual. The pullout Capacity of Concrete from PCI design Handbook for headed anchor or check bond and bearing for hooked anchor bolts.

5.4.3 SHEAR

For small embedment lengths, an anchor bolt loaded in shear will fail by pulling out of the concrete leaving a cone shaped hole. This mode of failure is very similar to that observed for bolts in tension. To develop its full resistance in shear, an anchor bolt must be embedded sufficiently to preclude the type of tensile pullout failure. Some procedure calculate the steel shearing resistance as the anchor's cross sectional area times the ultimate tensile strength of the steel. Another procedure calculates the steel shearing resistance using the shear friction concept. The summary of those procedures with reference is as shown in Table 1.



ANCHOR BOLT IN SHEAR

BEARING AND REINFORCEMENT PLACING

FIG. 14

According to Klingner's approach of References 35, 1, 8 is more rational insofar as it is based on experimentally observed failure.

For anchors close to a free edge three procedures shown in Table 1 References 35, 1, 8 idealize the concrete failure surface as a semicone whose height is approximately equal to the edge distance and whose sides have an inclination α. One procedure uses a variable, while the other two take equal to 45°. The concrete tensile strength is $4\sqrt{fc'}$ and acting perpendicular to this semiconical failure surface. The design strength of anchors in shear with large edge distance will usually be governed by steel capacity. The ACI 349 equation for concrete resistance is

$$V_{uc}' = 2\pi\, d_e^2 \sqrt{fc'} \times \phi \quad \text{------------(23)}$$

d_e = edge distance in inches

V_{uc}' = ultimate shear capacity per anchor in concrete

ϕ = 0.65 (recommended)

5.4.3.1 STRENGTH BY STEEL FAILURE

$$V_{us}' = \phi \times A_s \; (0.75\, f_{ut}) \quad \text{------------(24)}$$

f_{ut} = specified minimum ultimate tensile strength, Klinger suggests that the ultimate shear strength shall be taken 0.75 times the minimum specified tensile strength of the anchor.

V_{us}' = ultimate shear capacity of anchor in steel

ϕ = 0.90

5.4.3.2 CRITICAL EDGE DISTANCE

Side cover distance for anchor bolt, see Fig. 14 (b) loaded in shear towards a free edge shall not be less than

$$m = D\sqrt{\frac{f_{ut}}{7.5\sqrt{fc'}}} \quad \text{------------(25)}$$

5.4.3.3 AISC COMMENTARY

The AISC Commentary states "shear at base of a column resisted by bearing of the column base details against anchor bolt is seldom if ever critical. Even consider the lowest slip coefficient the vertical load on the column is generally more than sufficient to result in the transfer of shear from the column base by frictional resistance, so that anchor bolt usually experiences only tensile stress." The above statement is true for most multistory buildings, In case of industrial buldings uplift forces along with shear forces may exist simultaneously and designer must take care to transfer shear forces. There are several methods for shear transfer, anchor bolts is one of them.

Because of the oversize holes in the base plate, under the application of shear two bolts should be considered in bearing. The column under shear load will slip and rotate; two bolts can be considered in bearing, the bolts may not be able to deform sufficiently so that all the four bolts could be counted upon to carry load.

5.4.3.4 FRICTION

A rough guide of providing shear resistance in absence of gravity load dead or live is to pretighten the anchor bolts and transfer the load by friction based on initial preload in the anchor bolts and a coefficient of friction of 0.4 to 0.6 between concrete and steel allowable shear can be calculated. A rough guide to estimate the torque required to tighten anchor bolt is as follows:

$$\text{Torque} = K_1 P_d D \qquad \text{------------(26)}$$

K_1 = 0.2 for oily thread

P_d = desired pretensions

D = dia of bolt

Shown below the calculations to tighten a 2 inch diameter A36 anchor bolt to fy/2 = 18 k.s.i.

$K \approx 0.2$

$P_d = 0.5 \times 36000 \times 3.14$ (area of 2 ϕ bolt)

$= 56$ kips

$D = 2"$

$$\text{Torque} = \frac{0.2 \times 56 \times 2}{12} = 1.9 \text{ kip-ft.}$$

Depending upon the steel erector, may only require the described bolt load. These anchor bolts are pretensioned by hydraulic jack.

5.4.4 COMBINED SHEAR AND TENSION

Full embedment, normal weight and light weight of concrete, the equation should satisfy the following:

$$\left(\frac{P_u}{P_{uc}}\right)^{5/3} + \left(\frac{V_u}{V_{uc}'}\right)^{5/3} \leq 1 \qquad \text{--------------(27)}$$

where P_u and V_u are ultimate applied tension and shear.

P_{uc}' and v_{c}' are ultimate concrete capacities in tension and shear

5.4.4.1 Anchor subjected tension loading at a free edge

$$P_{uc}'' = \frac{2d_e}{9D} P_{uc}' \leq 0.85 \; f_{ut} \times A_s \qquad \text{--------(28)}$$

d_e = distance from the center of bolt to the free edge, in

D = diameter of bolt

P_{uc}'' = ultimate capacity of bolt in tension at free edge

5.4.4.2 Combined shear and tension for steel

$$\left(\frac{Pu}{P_{us}'} \right)^2 + \left(\frac{V_u}{V_{us}'} \right)^2 \leq 1 \qquad \text{------------(29)}$$

where P_u and V_u are applied load in tension and shear

P_{us}' and V_{us}' are the ultimate steel capacity in tension and shear

5.4.5 DEFORMED BARS

Deformed bars perform in an identical fashion to the headed concrete anchors except that the anchorage is dependent upon development length (bond) rather than an anchor head. The required length

$$\ell_d = \frac{0.03 \; D_b \; (fy)}{fc'} \qquad \text{------------(30)}$$

D = Dia of deformed bar

$fy \leq 60{,}000$ p.s.i.

The preceeding equation shall be multiplied by the quantity

$$\left(2 - \frac{60{,}000}{fy}\right)$$

Horizontal bars are placed so that more than 12 inches of concrete are below the bar (top bars only) should have above of ℓ_d multiplied by 1.4. The designation of top bars would apply only for the case where deformed anchors are acting as negative reinforcement. As used in some connection it is required to have a development length of 2 x ℓ_d as recommended by P.C.I.

5.4.6 FATIGUE

In cases such as trusses for highway signs, bolts are subjected to fatigue loading intension; special precautions must be taken. Assured petension in the bolts is important; however, the usual procedure for tensioning bolts in steel-to-steel joints are inapplicable or highly unreliable in anchor bolt application. According Fisher suggests if the net tensile stresses are kept to low levels of (6 to 8 k.s.i.), fatigue problems should not happen. If the anchor bolts are not tightened uniformly therefore the unequality may cause fatigue problems. In such cases designer shall specify all the anchor bolts be pretensioned to at least a magnitude which exceeds the applied design load and use of a detail which precludes reliance on natural bond. Prying action should be considered in tensile fatigue loads. The important factor of overload, tensile overload can cause yielding of bolt, the loss of initial clamping force.

5.4.7 BEARING

Bearing stresses between the base plate and concrete shall not exceed 0.85 x ϕ x fc' except when the support surface or foundation pedestal is wider on all sides than the loaded area, the permissible bearing stress on the loaded area may be multiplied by $\sqrt{\frac{A_2}{A_1}}$ but no more than 2 where

A_2 is maximum area of the portion of the supporting surface that is geometrically similar to and concentric with loaded are in in^2 or mm^2, and A_1 is loaded area in in^2 or mm^2. See CAN 3-A23.3-M77.

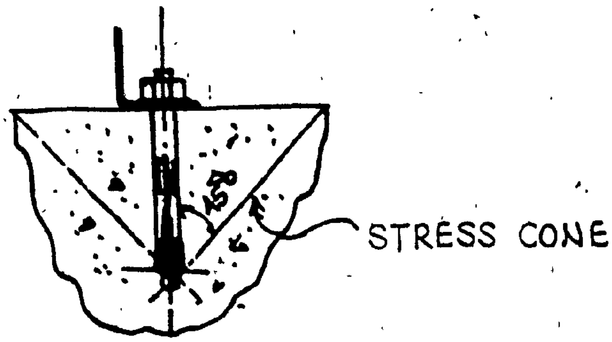
5.4.8 BEARING AND FRICTION TYPE BOLTS

Anchor bolts are assumed to bear against the concrete when shear occurs. The allowable shear values are enlisted in uniform Building Code 1973 edition, section 2.2 (Table 26-G), assuming 3000 p.s.i. concrete and continuous inspection. Minimum spacing is 13D and minimum edge distance is 6.5D. Such spacing and edge distance may be reduced to a maximum of 50% provided that the capacity is reduced linearly proportional to the decrease in spacing and edge distance.

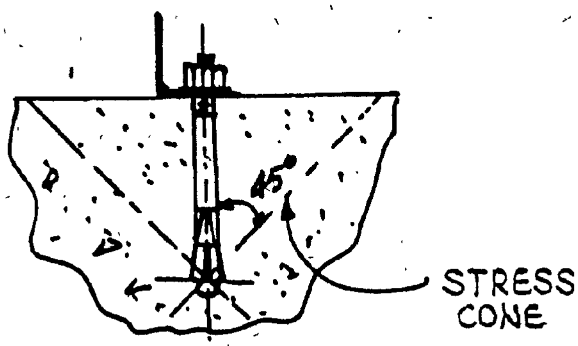
In case of friction type of bolt, friction between the base plate and concrete is introduced by prestressing the anchor bolts. The amount of shear resistance is proportional to effective prestressing force. A prestressing method should be evaluated to forecast the prestressing load on the bolt.

5.5 EXPANSION BOLT

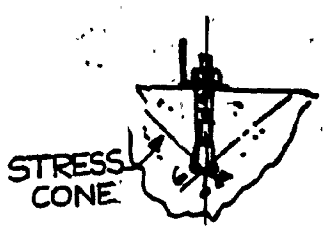
The pullout strength of concrete shall be same as in section 5.3.1 except that the effective area shall be defined by the projected area of stress cone radiating toward the concrete surface from the innermost



SLEEVE ANCHOR BOLT



WEDGE ANCHOR BOLT



ELF DRILLING
IEDGE ANCHOR

CAL DETAILS OF EXPANSION BOLTS

FIG. 15

expansion contact surface between the expansion anchor and drill hole. See Fig. 15. The minimum edge distance shall be twice of section 5.4.2.1. The general mode of failure for tensile loading expansion anchors is due to slip. Preloading of expansion bolt or anchors is not practical because of the slip characteristics of these anchorage.

The general failure in shear for group of self drilling anchors is shell failure at the bottom of the connecting bolt.

For expansion bolts with embedment depth of 4 bolt diameter or less, shear strength is influenced by the pullout strength of concrete even though failure in single bolt occurs in the bolt. Larger safety factors shall be used with expansion anchors.

Any manufacturer's claims which exceed the calculated pullout failure load as discussed under embedment requirements should be questioned.

The depth which most manufacturers show in their literature for setting the anchors e.g., cinch anchors appears to be based on the dimensions of the units and is a minimum to ensure only that the anchor units are in the hole. The workmanship is the prime important factor.

If the anchorage is to be in shear, the annular space between the concrete and the bolt shall be filled with a rigid material to prevent bending the bolt.

A single expansion anchor used to anchor an attachment shall be designed for one half of the design limits.

Tests shall be conducted by the testing agency other than anchor manufacturer and shall be certified by a professional engineer.

5.6 INSERTS

This is beyond the scope of the Technical Paper. For design requirement refer to A.C.I. Specification "Nuclear safety structures" and A.C.I. Sp. 22-10 "Industrial research on connection for precast and insitu concrete".

Table-1

Reference	Steel Failure	Concrete Failure Far From Edge - Cose to Edge	Comments
27	$V_{us}' = A_S \times f_{ut}$	$V_{uc}' = 1.106\ A_S \times fc'^{0.3} \times E_c^{0.44}$	fc', E_c in k.s.i. unit $E_c = 57 \sqrt{fc'}$, p.s.i.
		$V_{uc}'' = V_{uc}' \dfrac{(d_e - 1)}{8D}$	Short Edge Distance
28	$V_{us}' = A_S \times f_{ut}$	$V_{uc}' = A_S \times (0.9 \times f_{ut}$	
		$V_{uc}' = (2500\ d_e - 3500)$	Short Edge Distance
-	$V_{us}' = A_S \times f_{ut}$	$V_{uc}' = A_S\ (0.9\ f_{ut})$	
		$V_{uc}' = 3250\ (d_e - 1) \dfrac{\sqrt{fc'}}{\sqrt{5000}}$	Short Edge Distance
35	$V_{us}' = A_S \times f_{ut}$	$V_{uc}' = 6.66 \times 10^{-3} \times A_S \times fc'^{0.3} \times E_c^{0.44}$	f_c', E_c in p.s.i.
		$V_{uc}'' = V_{uc}' \dfrac{(d_e - 1)}{8D}$	Short Edge Distance
1	$V_{us}' = \dfrac{A_S \times fy}{c}$	$Vuc' = 2\ \pi d_e^2 \sqrt{fc'}$	$c = 1.0$ to 1.5
8	$Vus' = (AS \times 0.9 \times fy)$	$V_{uc}' = 2\pi\ d_e^2 \sqrt{fc'}$	Short Edge Distance
		$V_{uc}' = 2\pi \left[\dfrac{d_e + D/2}{\tan\alpha}\right]^2 \sqrt{fc'}$ $\alpha = (d_e + D/2)\ 4 + 25$ deg ≤ 45 deg	Short Edge Distance

Summary of Calculations
Nominal Shear Resistance

CHAPTER - 6

DESIGN EXAMPLES

CHAPTER - 6

DESIGN EXAMPLES

6.2 PROBLEM NO. 1

Design the base plate and anchorage for a W14 x 87 column that is subjected to axial load of 180 kips and moment of 205 ft-kips.

Solution: (Working Stress Method)

Assume A-36 steel fy = 36 k.s.i.

Using 4-bolts see Fig. 16.0

Step 1: Assume c/c of anchor bolt, bolt will carry the full moment, with 50% axial load to reduce the effect of moment, say 20"

$$\text{Approximate tension/bolt} = \frac{205 \times 12 - 0.5 \times 180 \times 10}{20 \times 2}$$

$$= 39 \text{ k}$$

Assume allowable tensile stress = 20 k.s.i. (on stress area)

$$\text{Approximate area/bolt} = \frac{39}{20} = 1.95 \text{ sq. in.}$$

Therefore try 2-1 1/2 ϕ bolts, stress area 2.81 sq. in.

Fix length of the base plate L = 27"

and width B = 28"

Step 2: Modular ratio $n = \dfrac{E_s}{E_c} = \dfrac{29000}{3000} = 9.66$

$$e = \frac{M}{P} = \frac{205 \times 12}{180} = 13.6"$$

Using beam anology method as described in section 5.2 and using the equations with three unknown X, T, ~~and C~~

$$x^3 + 3\,\Omega\,x^2 + \frac{6_n\,A_s\,(a \pm \Omega)}{B}\,x = 6_n\,A_s\,\frac{(a + \Omega)}{B} \times a$$

where Ω, n, a and B are shown in Fig. 9

Plus sign will apply when the equivalent load line falls outside the leeward edge of the base plate, while minus sign will apply when it falls within the base plate. The simple way to solve the above equation, plot a few points on a graph. Let x_1 be equal to some simple whole number for example 10, 12, 13, etc, and plotting the value and then read the value of x_1 on the graph where curve crosses zero.

Let x_1 = 10, 13

1000 + 60 + 1407.6 - 3378.24 = 910.24

Say -910

Also x_1 = 13

2197 + 101.4 + 1829.88 - 3378.24 = +750

Reading the values while plotting values of

x_1 -910 and +750

x_1 = 11.75"

Check when x_1 = 11.75"

1622.22 + 82.83 + 1656.28 = 3378.24

3361.33 = 3378.24

(Close enough)

Tension in bolt $T = \frac{P(x + 3\Omega)}{3a - x}$

$= 180 \frac{(11.75 + 3 \times 0.2)}{3 \times 24 - 11.75}$

$= 36.89^k$

Actual tensile stress $= \frac{36.89}{2.81}$

$= 13.13$ k.s.i $<$ 20 k.s.i.

Allowable bearing stress $= 0.35\ fc' \sqrt{\frac{A_2}{A_1}} \leq 0.75\ fc'$

where A_2 is the area of concrete pier and A_1 is the area of the base plate, assume $\frac{A_2}{A_1} = 3$

Therefore allowable bearing stress $= 0.35 \times 3000 \sqrt{3}$

$= 1.8$ k.s.i.

Step 3

Stress in concrete $= \frac{2\ (P + T)}{B \times X}$

See equation (16)

$= \frac{2\ (180 + 36.89)}{28 \times 11.75}$

$= 1.31$ k.s.i. < 1.8 k.s.i.

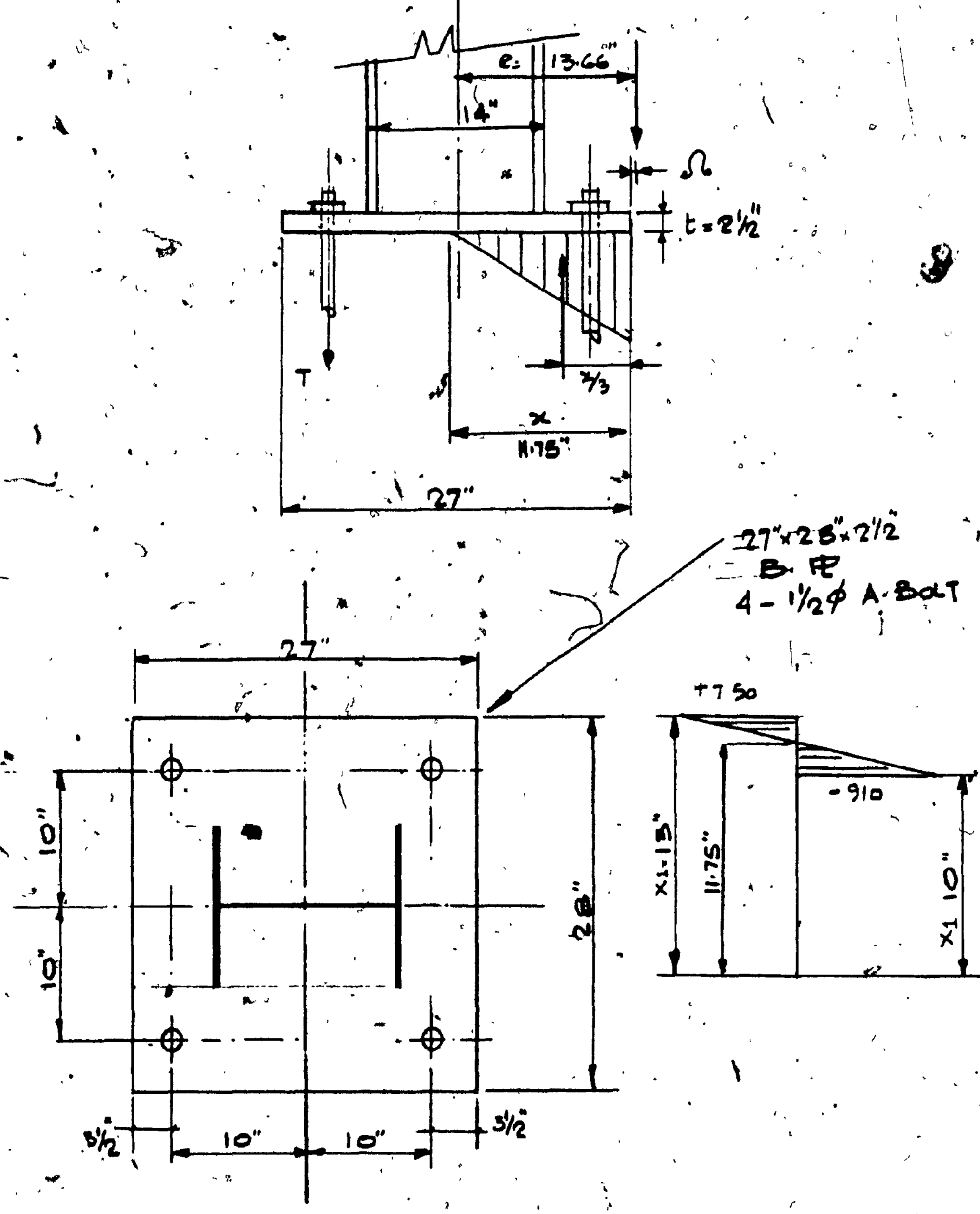
(O.K.)

Step 4

Base Plate Thickness

The critical moment in the base plate is at the center of leeward flange or use C.I.S.C. method such that projection $= \frac{27 - 0.95 \times 14}{2}$

$= 6.85"$



COLUMN BASE PLATE AND ANCHOR BOLT DESIGN

FIG. 16

Moment at face of column

$$= 0.54 \times \frac{6.85^2}{2} + \frac{1}{2} \times 0.76 \times 6.85 \times \frac{2}{3} \times 6.85$$

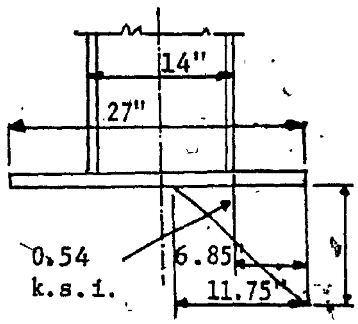
$$= 24.55 \text{ in-kip/in}$$

Thickness of plate $t = \sqrt{\frac{6M}{F_b}}$

$$F_b = 0.75 \times F_y = 27 \text{ k.s.i.}$$

$$t = 6 \times \frac{24.55}{27}$$

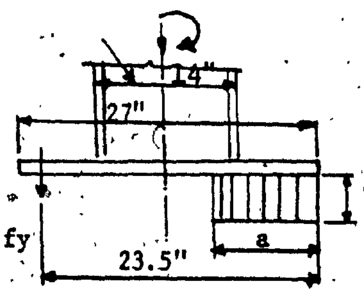
$$= 2.33\text{" Say } 2\ 1/2\text{"}$$



Use 28" x 2 1/2" x 27" base plate, 4 - 1 1/2 ϕ

Anchor bolt see Fig. 16.0

Second Method (Ultimate Strength)



The precise distribution of stress on the support is unknown.

In this case stresses zone of concrete is only a portion of the whole support, thus local crushing strength is raised therefore conservative value of 0.85 fc' is used. Assuming the base plate as calculated above by working stress method and anchor bolts (27" x 28" x 2 1/2" , 4 - 1 1/2 ϕ bolts) let us find the ultimate capacity of the plate.

$$e = \frac{M}{P} = \frac{205 \times 12}{180} = 13.66"$$

using equation (18)

$$P_u = 0.85 \times 3 \times a \times 28 - 2.81 \times 36$$

where fc' = 3 k.s.i. Area of two bolts = 2.81 sq. in.

(tensile stress area)

$$a = .014\ P_u + 1.41$$

using equation (19)

$$P_u \times 13.66 - P_u\,(13.5 - \frac{a}{2}) = 101.16\,(23.5 - \frac{a}{2})$$

Substitute the value of a we get

$$P_u = 472.7 \text{ kips}$$

$$M_u = 472.7 \times \frac{13.66}{12} = 538.18 \text{ k-ft.}$$

$$a = .014 \times 472.7 + 1.41 = 8.02"$$

$$\text{Moment at 6.85" projection} = 0.85 \times 3 \times \frac{6.85^2}{2} = 59.82 \text{ K-in/in}$$

$$M_p = \frac{1}{4} \times fy \times t^2 = \frac{1}{4} \times 36 \times 2.5^2 = 56.25 \text{ K-in/in}$$

$$M_u \approx M_p \quad \text{(O.K.)}$$

$$S_F = \frac{472.7}{180} = 2.62$$

Therefore safety factor in ultimate design is 2.62.

Simplified Method (Working Stress)

In this method location of centroid of the compresson is important. If the plate is too thick the rotation will take place at the edge of the plate and if the plate is thin it will take place under the leeward column flange. Assume the thickness of plate after calculating the bolt sizes.

Step 1. Same as shown on page 67

Therefore by 2-1 1/2 0 bolts on either side of the base plate.

The plate thickness should be more or less of same thickness.

Step 2 Fixing length of base plate L = 27"

A_s = 2.81 sq. in. (2 bolts)

T = 2.81 x 20 = 56.2 kips

Allowable bearing stress = $0.35\ fc' \sqrt{\frac{A_2}{A_1}}$ or 0.6 x fc'

= 0.6 x 3000 = 1.8 k.s.i.

Step 3, Let us assume distance x for the triangular pressure as one third of the length i.e., 27" say 9 inches.

Compression force = $\frac{1}{2}$ x 9 x 1.8 x B

B = Width of plate

Summation of vertical forces i.e., V = 0

180 + 56.2 = $\frac{1}{2}$ x 9 x 1.8 x B

B = 29.16" Say 29"

Thickness of the plate can be calculated at the face of column flange.

Projection $= \frac{27 - 14.0}{2} = 6.5"$

Width of column flange = 14.5"

Depth of column = 14"

Bearing pressure under the face of column $= \frac{1.8}{9} \times 2.5 = 0.5$ k.s.i.

$$M = 0.5 \times \frac{6.5^2}{2} + \frac{1}{2} \times 1.3 \times 6.5 \times \frac{2}{3} \times 6.5$$

$= 28.86$ in-kip/inch

Thickness of plate $t = \sqrt{\frac{6 \times M}{F_b}} = \frac{6 \times 28.86}{27}$

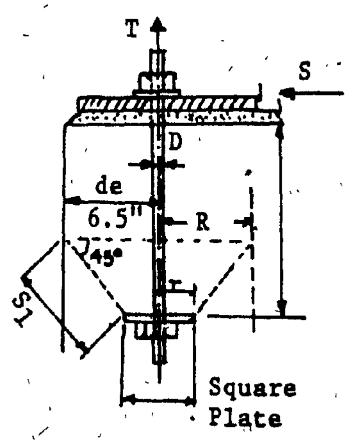
$= 2.53"$ say 2 1/2"

Therefore 27" x 2 1/2" x 29" base plate, 4 - 1 1/2 ϕ anchor bolt can be used.

From the above method applying a reasonable judgement, base plate thickness and anchor bolts can be calculated without involving complex equations.

PROBLEM NO. 2

Determine the pullout capacity and shear capacity of 1" anchor bolt (as shown in the figure below) with embedment length of 12D, edge distance of 6.5D. Use A-36 steel bolt Fy-36 k.s.i. concrete fc' = 3000 p.s.i. Calculate anchor plate size and thickness for the anchor bolt.



ANCHORAGE DESIGN

Fig. 17

Solution:

Given data

A_g = Gross area of bolt = 0.79 sq. in.

A_s = Stress area of bolt = 0.606 sq. in.

Fy = 36 k.s.i.

Fc' = 3000 p.s.i.

Tensile capacity of bolt in concrete

$P_{uc}' = 4 \phi \sqrt{fc'} \times A_O \times c$ (see section 5.4.2)

c = 1.0 for normal wt concrete

ϕ = 0.65

A_O = Concrete cone surface area

$= \pi S_1 (R + r)$

$S = 2 \times (6.5" - 1.75")$ where $R = d_e = 6.5"$

$= 6.71$ $r = \frac{3.5"}{2}$

$A_o = 3.14 \times 6.71 \; (6.5 + 1.75)$

$= 168.74$ sq. in.

Ultimate strength in tension

$P_{uc}' = 4 \times 0.85 \sqrt{3000} \times 168.74$

$= 31.42$ kips

Tensile capacity of steel (see section 5.4.2.2)

$P_{us} = \phi \times fy \times A_s$

$\phi = 0.9$

$= 0.9 \times 36 \times 0.606$

$= 19.63$ kips (governs)

Hence ultimate capacity of 1" ϕ bolt in tension is 19.63 kips or

service load capacity $= \frac{19.63}{1.7} = 11.54$ kips (assume 1.7

as live load factor)

<u>Shear Capacity of Bolt</u>

Shear capacity of concrete

$V_{cu} = 2 \pi d_e^2 \sqrt{fc'} \times \phi$ (see section 5.4.3)

$\phi = 0.7$

$= 2 \times 6.5^2 \sqrt{3000} \times 0.7$

$= 10.17$ kips

Shear capacity of steel (see table -1)

$= \frac{A_s \times fy}{C_1}$ $C_1 = 1.5$

$$V_{su} = \frac{A_s \times fy}{1.5}$$

$$= \frac{0.606 \times 36}{1.5} = 14.54 \text{ kips}$$

Therefore the shear capacity of bolt is 10.17 kips (ultimate)

Service load capacity $= \frac{10.17}{1.7} = 5.98$ kips

Anchor plate size

Ulitamte bearing capacity $= 0.85\ fc' \times 0$

$= 0.85 \times 3000 \times 0.7$

$= 1.8$ k.s.i.

Area required for plate $= \frac{19.63}{1.8}$

$= 10.9$ sq. in.

where 19.63 kips is tensile capacity of bolt

Use 3 1/2 x 3 1/2" plate, so that

$$M_u = 1.6 \times \frac{(3.5)^2}{2} = 4.90 \text{ in-kip}$$

Where 1.6 k.s.i. is the actual bearing pressure

$$M_R = 0.9 \times fy \times \frac{t^2}{4}$$

$$t^2 = \frac{4 \times 4.90}{0.9 \times 36}$$

$t = 0.77$ " Say 3/4" thick

Therefore provide 3 1/2" x 3 1/2" x 3/4" anchor plate for 1" ϕ anchor bolt.

CHAPTER - 7

MISCELLANEOUS ANCHORAGES

Chapter - 7

MISCELLANEOUS ANCHORAGES

7.1 MACHINE FOUNDATION ANCHORAGE

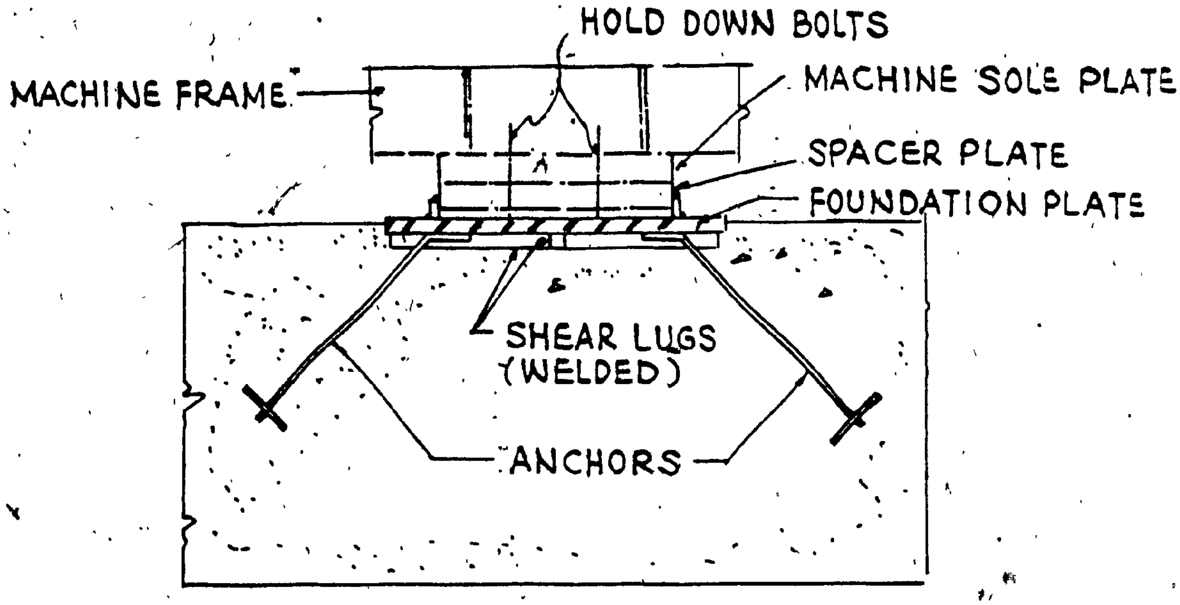
7.1.1 BASE AND SOLE PLATES

The rotating machines produce dynamic and vibratory effects such that the machines be rigidly connected to their foundations. Steel base plates or frames are used in most of the machines and in addition embedded anchor bolts to maintain the stability and machine alignment. Holes in the base plates are wider to accommodate necessary construction clearance between the anchor bolt and the base plates. This can create large movements of the machine before the anchor bolt engages the base plates.

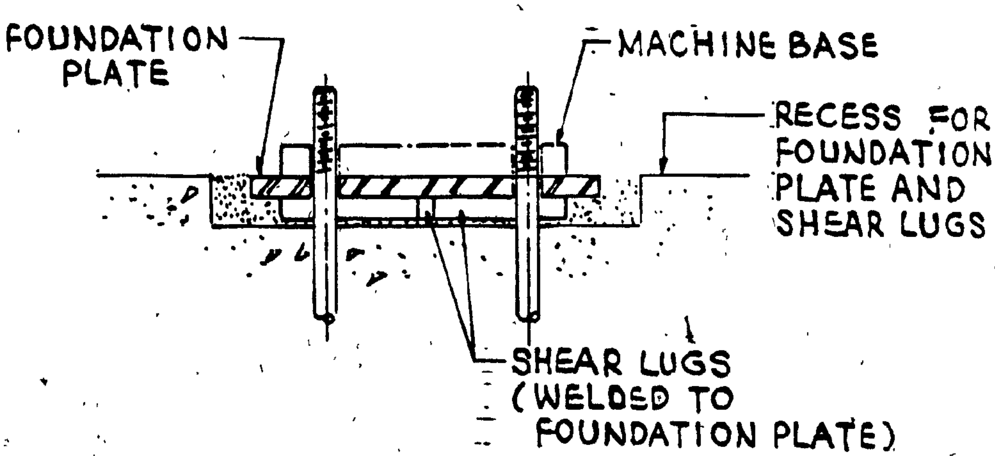
Rotating and reciprocating machines can cause large shears and vibrations require the movement to be restricted. Shear lugs and anchors are welded to foundation plate and this foundation is cast with foundation plate and roughly levelled ($\pm$ 3/8") once the concrete is set another plate on top of the foundation plate being accurately levelled and welded to the foundation plate, see Fig. 18(a). Attached shear lugs and anchors directly in concrete provides shear resistance.

Another detail shown in Fig. 18(b) is for foundation plate, can be used for machine with large horizontal shears with embedded anchor bolts with sufficient embedment length, edge distance and spacing. The foundation plate with welded shear lugs is accurately levelled in the recess provided in concrete foundation and is dry packed with nonshrink grout under and around the foundation plate and shear lugs.

For less severe vibration and shear loading shear lugs are not required and detail 19(b) can be used. A small recess in concrete will

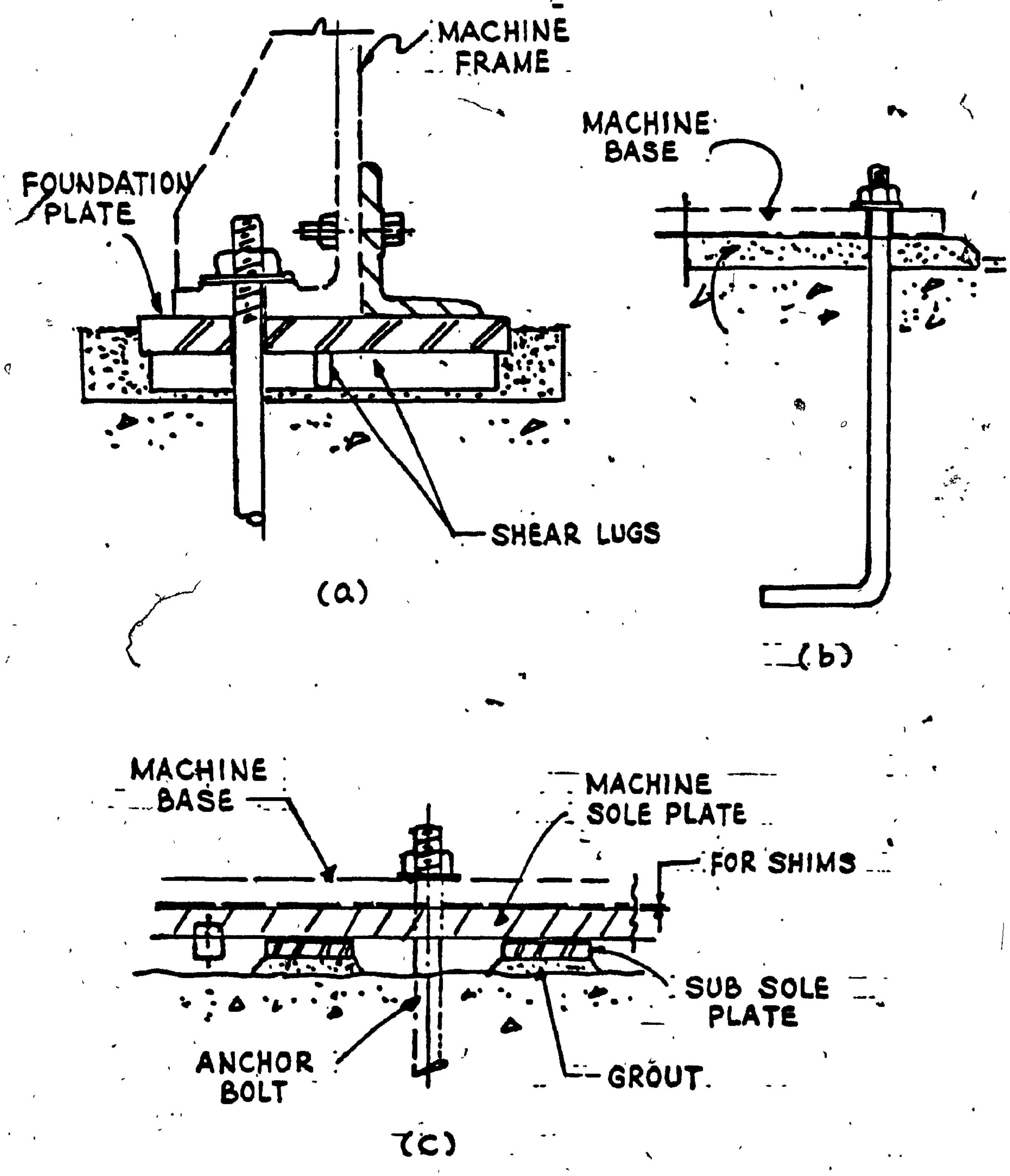


MACHINE ANCHORAGE
(WELDED CONNECTION)
(a)



MACHINE ANCHORAGE
(BOLTED CONNECTION)

FIG. 18



MACHINE ANCHORAGE DETAILS

FIG. 19

clinch the grout in place in case it cracks.

To reduce the shear from the machine to the foundation plate without the plate slippage required to engage the anchor bolts, a structural angle with stiffness may be bolted to machine frame and welded to foundation plate, see Fig. 19(a).

See detail 19(c) sub-sole plate is set on grout. The grout for sub-sole plate shall be made of the highest grade material and workmanship.

7.1.2 ANCHOR BOLTS

Various types of anchor bolt are shown in the Fig. 20, sleeves are provided for adjustment. If sleeves are not provided then the bolt must be positioned with a template. For large anchor bolts are usually stud bolts with square nuts, see Fig. 20(b,c). Closely spaced anchor bolts shall have a common anchor plate.

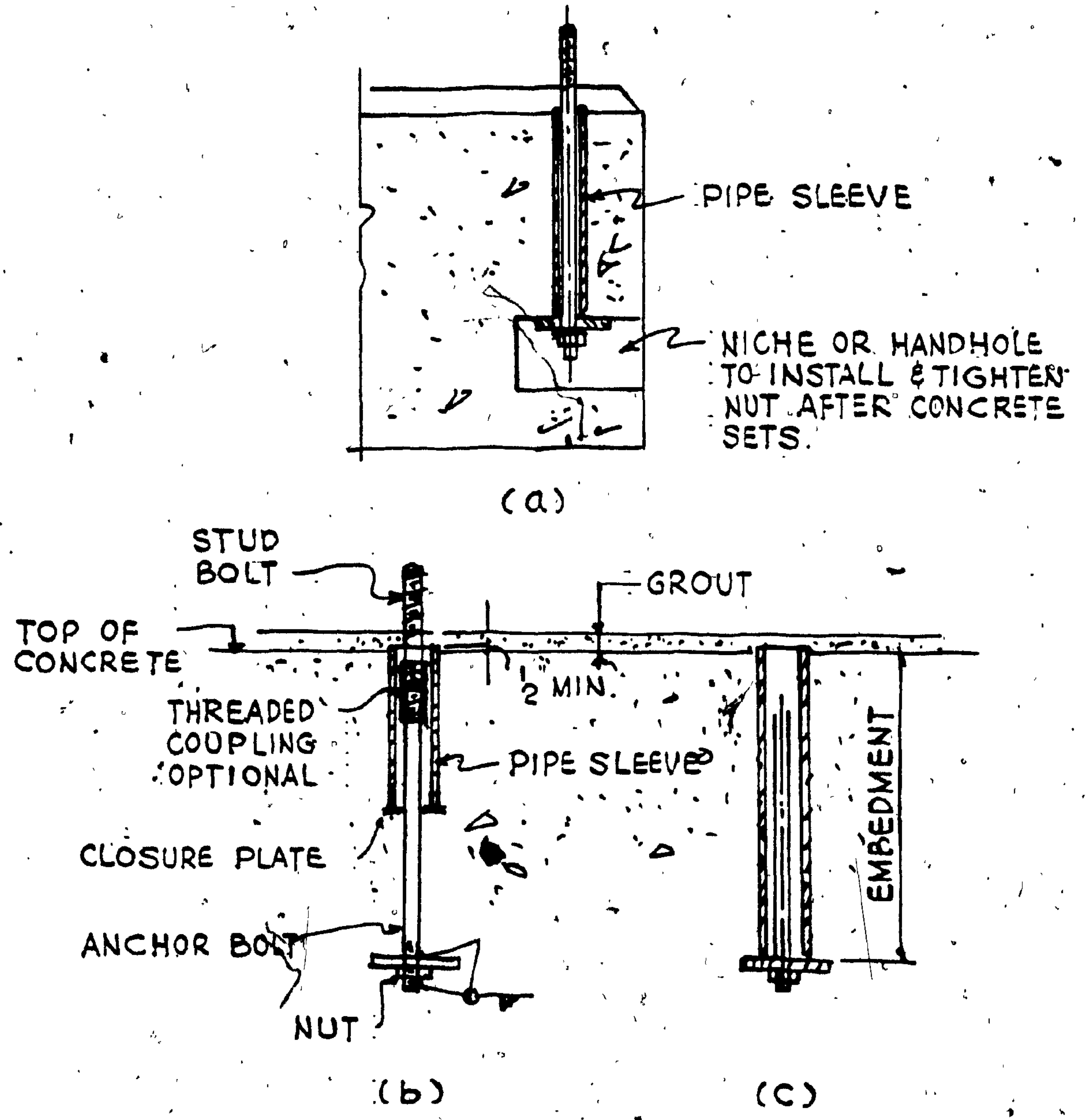
The detail is applicable, see Fig. 20(a) when the anchor-bolts can be inserted from above, accessible handholes are provided in the concrete foundation with threaded stud bolts.

To reduce the shrinkage cracks in the vertical faces of concrete steel templates should be used in case of large machines.

The lower ends of the anchor bolts are tied with wire to the reinforcement to prevent movement.

The embedded and grouted anchor bolts are usually used in the machine foundations. Inserts and expansion anchors are not recommended for large vibrating mahcines, unless listed and certified.

Embedded pipe sleeves and anchor bolts tend to cause phases of weakness, especially if two or more are together. This is serious in



MACHINERY ANCHOR BOLT DETAILS

FIG. 20

case of machinery where the shocks cause a bearing of the bolt against concrete. Therefore either proper edge distance should be provided or the area around the sleeve is confined by using "hairpin" rods.

7.2 MASSIVE FOUNDATION ANCHORAGE

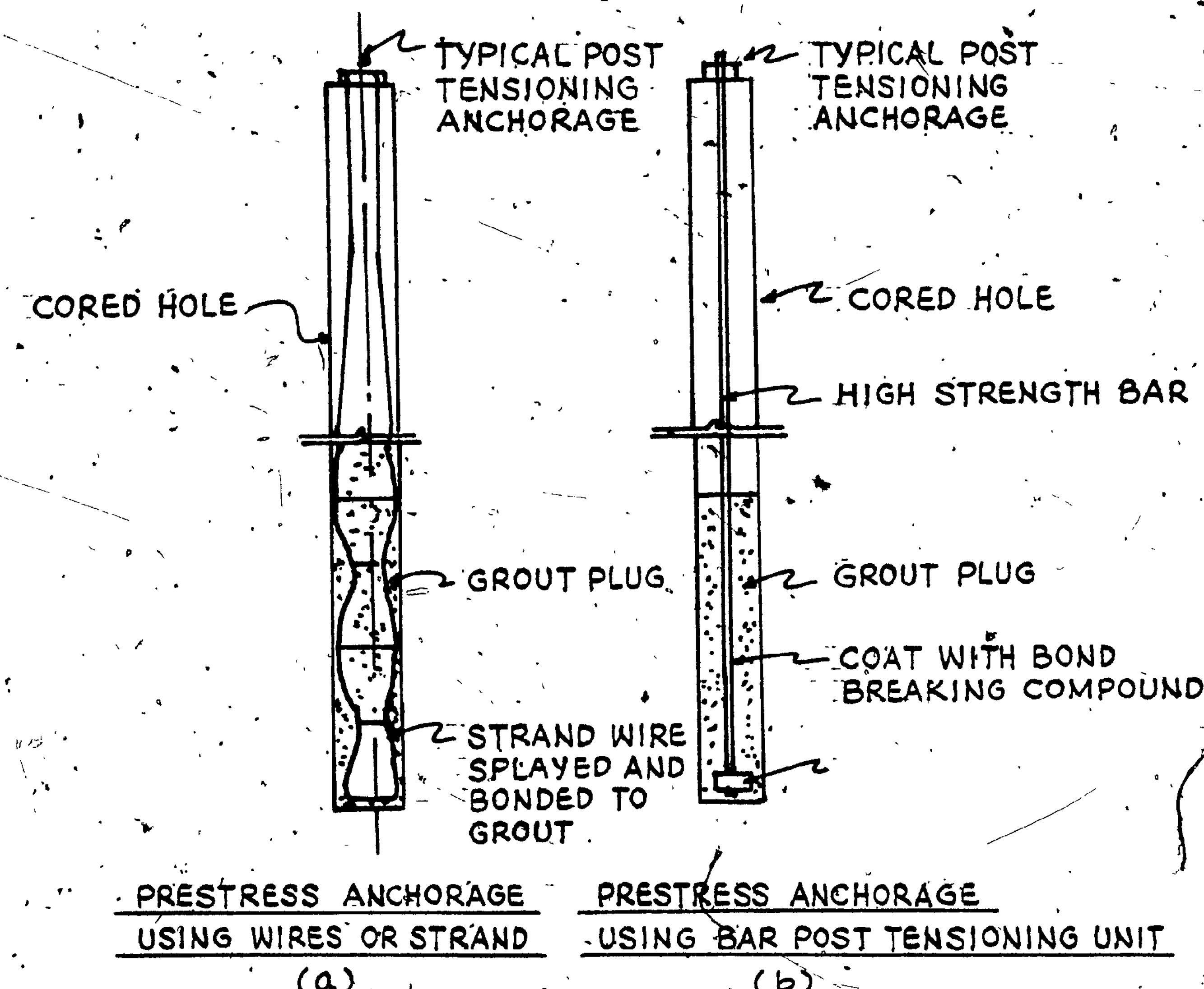
To anchor dome and spillways, high strength wires are placed in a cored hole. A grout is poured, when the grout has gained strength the unit is post tensioned, see Fig. 21(a). In this case force is transmitted through tension in the tendons and transferred to the concrete plug through bond between tendons and concrete.

The depth of the plug must be assumed greater than that which should be required for safe anchorage of the plug. The another suggested detail see Fig. 21(b), prestressing is also transmitted through tension in tendon but this force is anchored to the plug by compression. The plug acting in compression transmits stress through shear to the cored hole. Since bond value is not known which is also in Fig. 21(a), no additional length of the plug is provided to account for tendon bond transfer.

7.3 ANCHOR BOLT PROBLEMS IN THE FIELD

Material handling people usually complain about the obstruction and interferences due to the projections protruding out of the slabs. They are usually out off the line. The bolts are hammered to bend or even burned to fit them into the holes. Some details are presented by various people are shown for reference, see Fig. 22(a to f).

a) Outcase of required length from any standard pipe, threaded inside case for anchor bolt in standard length. The ball-joint socket assures a slight rotation.



MASSIVE FOUNDATION ANCHORAGE

FIG. 21

b) The sleeve is welded to the plate but the bottom of the bolt is free. Top of the bolt held in timber with threaded nails holding sleeve in position. The whole assembly is rigid till the concrete is poured. After the concrete is preset the timer is removed, the bolt is loosened to move into metal cover.

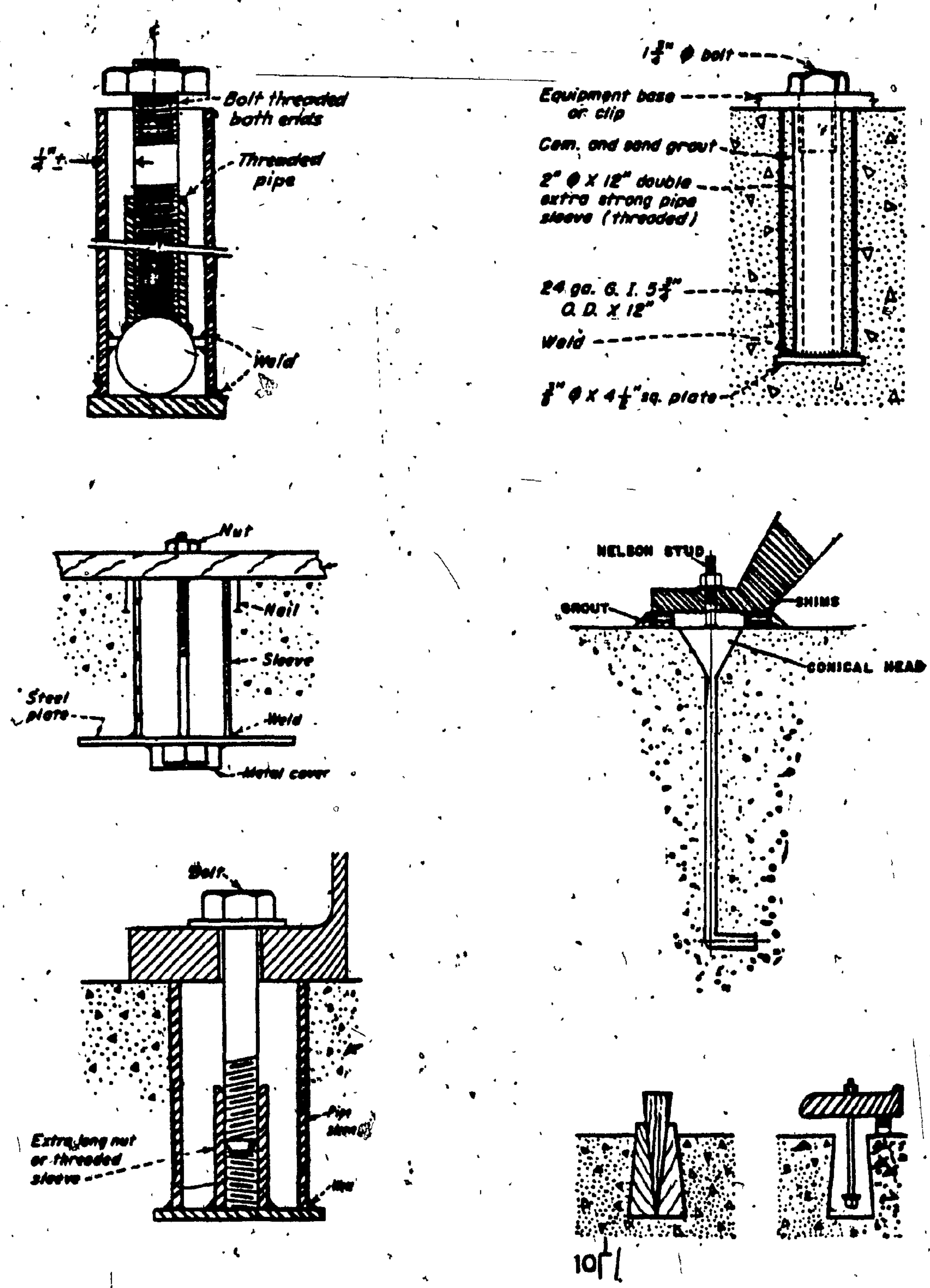
c) See Fig. 22(c)

d) It is provided with a conical head anchor bolt together with Nelson studs as shown. The conical head would give reasonable tolerance.

e) See Fig. 22(e)

f) See Fig. 22(f)

These are suggested solutions which should be further improved in view of their strength, economics and reliability.



ANCHOR BOLT DETAILS SUGGESTED TO AVOID FIELD PROBLEMS

FIG. 22

CHAPTER - 8

CONCLUSION

Chapter - 8

CONCLUSION

"Experience is a trophy composed of all the arms with which we have been wounded" said Costa de Rels. Reliability, economy, and simplicity are always the prime leaders of consideration whether an anchorage requires a thousand cubic meters of concrete, large anchor bolts or a small base plate connection. When providing an anchorage, good or bad, cost has only a nominal effect on the overall construction. Simplicity is an understanding that is directness of expression and restraint in ornamentation the final concept of the connection to perform.

Whether a small stub or a machine foundation, the anchorage must be adequate to do the task assigned. Therefore a clear understanding of this task is of utmost importance.

Reliability means performance and an added assurance against fatigue, corrosion and other time dependent effects. Quality, which is difficult to define in each anchorage is workmanship. The most sophisticated or the highest does not necessarily mean quality. The client's requirements always form the foundation of quality. In particular, quality is the major responsibility of those who are closest to the Engineering and Construction operations.

Problems often occur because of lack of coordination between trades. This is often lack of communication and mutual understanding of the permissible limits is misalignment for the two components connected.

Every now and then, in spite of all the codes and factors of safety provided newspaper clippings record some catastrophic happening /

somewhere in the world. Structures have collapsed in the past, and even with highly improved technology they will probably continue to do so. But today science is trying to build up their fail-safe nature where total collapse is prevented or sufficient warning is given.

Base plate design with concentric loads by A.I.S.C. or C.I.S.C. method as explained in the Handbook and Chapter Six is conservative and gives sufficient factor of safety. In some cases, however, under heavy lateral loads due to earthquake or blast, rotation of base plate can cause high stresses in the frame which may not be the part of original design. Judgement should be applied studying carefully the anchorage between foundation and soil to keep such risk low. It is wise to use low stresses for the design of anchor bolts. The forces under the base plate are complex. Since discontinuity does occur at the base plate and concrete as discussed earlier in a previous chapter, the use of Beam Analogy method while approximate gives a fair amount of safety. Ultimate method is a more realistic analysis, however, it does neglect the influence of confinement which exists in the base plates on foundations of bigger area. Moment rotation analysis should be verified under these conditions.

The proposed method is simple and can provide a reliable anchorage. The concrete stress is quite sensitive to the location of resultant compression, depending upon the load and thickness of plate, therefore keeping in mind the complexity of stress to refine the location is misleading.

The other most important key element that anchorage has is proper embedment. When the requirements for embedment are met, along with edge distances and spacing between the anchors, the failure is restricted to the material strength.

Embedment can be assured by equating the pullout cone strength of the concrete to the tensile strength of the anchors using a uniform concrete tensile stress of $4 \phi \sqrt{fc'}$ acting on a projected area confined within the limits of intersecting cones radiating from the heads of bolts at the base of the anchorage. A reduction in capacity of the anchor should be assumed in case when an anchor is located near a free edge or if the spacing of anchors is less than as indicated in section 5.4.1. It has been suggested that this capacity is in proportion to the reduction of the surface area of the cone.

The shear strength of anchorage depends upon the strength of the bolt and the method of attachment. When the anchors are loaded in shear towards a free edge, their shear capacity may also be affected.

Under combined loading of tension and shear, basic failure modes are: failure of the stud anchor, severe concrete cracking and concrete cone pullout. Anchor bolts with square or round welded plate or held with nuts are recommended.

Anchor bolt strength in combined shear and tension will be controlled either by the bolt material in combined shear and tension or by the concrete under combined shear tension. To check the combined stresses in the bolt material, A.I.S.C. interaction equations are to be used. The P.C.I. Handbook contains procedures determining the concrete strengths. The Engineer should be careful when working with concrete strength equations, since they are always written in ultimate strengths terms.

Bolts grouted into drilled holes (with roughened sides) provide the same anchorage strength as in cast-in-place anchors. Length and factors are included in the design.

The general mode of failure of expansion bolts is anchor slip. Workmanship is one of the most important factors in expansion bolts. Expansion bolts usually are not recommended for heavy vibratory machines. If used, these bolts should be tested by the proper agency and verified by qualified professionals. A larger safety factor should be used with expansion bolts to limit the deflection.

For expansion anchors with embedment of 4 bolt diameter or less, shear strength is influenced by the pullout strength of concrete even though failure in single bolt tests occurs in the bolt.

The recommended details of anchorage for machine foundation should be further verified with dynamic analysis. The use of specific details shown here is not mandatory. Anchor bolts should be further verified to provide strength and rigidity to handle field detail complaints.

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