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Development of Data Model for Large-Scale Structural Experiments, C-H. Lee

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ATLSS Report No. 06-16

December 2006

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ABSTRACT

Large-scale structural experiments are carried out to evaluate and improve the performance of members, connections, frames, and other assemblies. The laboratory specimens used in these experiments are placed in experimental facilities, loading histories are applied, and data are generated. For structures subjected to simulated earthquake loadings, pseudo-dynamic test methods can be used to overcome the size limitations of shaking table tests. To avoid fabrication and testing of an entire structure, hybrid pseudo-dynamic tests can be used to combine physical substructures and analytical substructures in a single experiment. The information related to these large-scale structural experiments is often complicated and stored in various documents, drawings, photos, and other computer-based files. A data model is needed to efficiently access, share, and use this information. This report describes a data model for large-scale structural experiments, developed at the Real-Time Multi-Directional (RTMD) testing facility at the ATLSS Center at Lehigh University. The RTMD facility is an equipment site within the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The data model is called the Lehigh Model. The development of the Lehigh Model is based on the thorough review of the previous data models and a study of recent large-scale structural experiments conducted at the ATLSS Center. The Lehigh Model has class hierarchies consisting of the project, experimental task, test condition, and test classes to organize and represent information about structural experiments. These classes are illustrated using steel moment connection tests as an example.

CHAPTER 1

INTRODUCTION

This report presents a data model, called the Lehigh Model, for the information and data related to large-scale structural experiments. The data model was developed at the Real-Time Multi-Directional (RTMD) testing facility at the ATLSS Center at Lehigh University. This chapter of the report provides a brief introduction to data models and presents the objectives and an outline of the report.

1.1 Need for Data Models for Structural Experiments

Structural researchers perform laboratory experiments to examine and understand the behavior of structural components, connections, and assemblies and to develop ways of enhancing this behavior. Often these experiments are conducted at large-scale on complex structural assemblies. The experiments may involve one or more test methods, including quasi-static, pseudo-dynamic, or hybrid pseudo-dynamic test methods, to closely simulate realistic loading conditions. The results from these experiments (i.e., the test or experimental results) are published in papers and reports, shared with other researchers, and used for related research and practical applications. For simple structural tests, the related information and data can be easily organized and managed. As the experiments become more complicated due to the large scale, the complexity of the test specimens, or the sophistication of the experimental methods, the amount and complexity of the related information often increases remarkably.

The large amount and diversity of the information related to structural experiments, including the data files, drawing files, photos, videos, researcher's notes, and other descriptions of the test specimens, test facility, test methods, and test fixtures, make it difficult to efficiently access, share, and use the information. The relationships among the different types of information (e.g., among the test data, the drawings for different specimens, photos of different tests, and the test methods employed in different tests) are often unclear and perhaps misleading to other researchers who may try to use the data after the experimental research project is complete. In addition, organized (structured) searches to locate specific elements of the information are often impossible. Even the research team who conducted the experiments may have difficulty in efficiently accessing and using all of the details of this information. As a result, while the main concepts from the structural experiments may be disseminated in standard papers and reports, many interesting and important details of the experiments may not be readily available or easily shared.

A data model for structural experiments can be used to organize and represent the related information and data. A data model helps researchers logically organize and manage the information and data from structural experiments using predefined hierarchies and categories of information. The logical organization of the information enables relationships among information to be established, enables missing information to be identified, and enables structured searches to locate specific elements of the information. Once the data model is implemented, the implemented model provides structural researchers with a convenient means to access, share, and use the information.

If the implemented model can be accessed through the internet, then a wide range of researchers and practitioners can access and use the results from the structural experiments.

In the past, several databases for structural test data have been created to provide researchers and practitioners with access to specific sets of test data. In addition, several efforts to develop data models for earthquake engineering research have been undertaken in support of the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES), which is a shared national network of 15 experimental facilities in the United States, linked by NEES information technologies [NEESit, 2006]. The data models developed previously for NEES have been useful for organizing general information about large-scale structural experiments, as well as information for other types of earthquake engineering research, such as shake table experiments or tsunami wave basin experiments. More detailed data models for structural experiments are needed, which include specific categories of information that were not developed in the previous models, such as the test condition details.

1.2 Objectives of Report

To organize and represent information and data related to large-scale structural experiments, so that this information and data can be accessed, shared, and used efficiently, a data model for structural experiments has been developed. This report describes this data model, called the Lehigh Model, which was developed at the Real-Time Multi-Directional (RTMD) testing facility at Lehigh University, one of the equipment sites within NEES. The objectives of this report are:

1. To summarize the background and basis for the model;
2. To present the model in terms of the classes and attributes which represent categories of information and data related to structural experiments, and in terms of the relationships among these classes and attributes which represent the relationships among these categories of information and data; and,
3. To illustrate the model by applying the model to large-scale experiments which were conducted at the RTMD facility at Lehigh University.

1.3 Outline of Report

This report starts with the present chapter, which outlines the need for a data model for large-scale structural experiments. Chapter 2 reviews previous work on data models and databases for structural test data, which provides the background for the Lehigh Model. Chapter 3 presents the formulation of the Lehigh Model, and Chapter 4 presents the model in further detail in terms of classes and attributes and the relationships among these classes and attributes. Chapter 5 presents an illustration of the model by applying the model to large-scale experiments. Chapter 6 summarizes the report and provides recommendations and conclusions.

CHAPTER 2

PREVIOUS WORK ON STRUCTURAL TEST DATA

This chapter briefly summarizes selected previous research on data models and databases for structural test data, which provides the background for the Lehigh Model. Three data models and two databases for structural tests are reviewed.

2.1 Previous Work on Data Models for Structural Tests

The fundamental concepts of data models for structural tests as well as some basic classes and attributes have been developed by previous research. This section presents a brief summary of this work.

2.1.1 Reference NEESgrid Model

A data model called the "Reference NEESgrid Model" was developed at Stanford University by Peng and Law (2004) to define the data requirements for NEES. This data model was focused on shaking table experiments, but many aspects of this model are relevant for other types of structural experiments. The Reference NEESgrid Model includes six base classes, which are designed to represent shaking table test data. The six base classes are the SiteInformation class, the Activity class, the Apparatus class, the ApparatusSetup class, the DataElement class, and the ComplexDataType class. Each base class has subclasses, and the relationships among the five of the six base classes and their subclasses are presented in Figure 2.1. The figure does not include the ComplexType class because its purpose is to support other base classes and their subclasses. The subclasses of the Activity class represent the primary activities that generate the experimental results. This hierarchy of subclasses shows that the Project contains Tasks, each Task contains EventGroups, and each EventGroup contains Events. An Event generates a unique OutputData from a structural test.

2.1.2 Oregon State Model

A data model, referred to herein as the "Oregon State Model", was developed by Oregon State University and the Northwest Alliance for Computational Science and Engineering (Oregon State University, 2003) to represent test data from tsunami wave basin experiments, as part of the development of the NEES equipment site at Oregon State University. This data model is based on the relational data model. A high-level entity-relationship (E-R) diagram for the data model is presented in Figure 2.2, which represents the relationships among projects, experiments, equipment, researchers, experimental results, and so on. The figure shows that a project may have multiple experiments, an experiment may have multiple configurations, and a configuration may have multiple trials, and the output data is produced by a trial. The data model includes a relatively small number of entity classes.

2.1.3 NEEScentral Model

The “NEEScentral Model” is recently developed for NEES to provide classes to represent information for structural and other earthquake engineering experiments. The implementation of this data model is intended to be an application that allows users to store and retrieve the test data via the internet (NEESit, 2006). Figure 2.3 shows the relationship among the classes in a high-level class diagram. The NEEScentral Model is the intended to allow users to search for the test data according to projects, experiments, organizations, and facilities. The data model includes a significant number of classes and attributes to enable users to represent information related to test data, such as the Material Property class to represent related material information, the Coordinate Space class to locate sensors or other equipment used in the experiments, and so on. The main activities of a research project represented hierarchically in the data model include the Project, the Experiment, the Trial, and the Repetition which ultimately generates test results.

2.2 Previous Work on Databases for Structural Tests

Previous work on databases for structural test data suggests the types of detailed information about structural tests that are relevant and should be included in a data model. This work also suggests the types of data that should be searchable within a database that implements the data model. This section presents a brief summary of previously-developed databases for structural tests.

2.2.1 SAC Design Information Database

The SAC Design Information Database includes steel connection test data from tests conducted after the 1944 Northridge Earthquake (http://www.sacsteel.org/, 2006). The database includes test descriptions and results from the 278 tests that were summarized in FEMA 289 (FEMA, 1986). The test data in the database are organized according to properties of the test specimens, including member size, connection type, material strength, beam and column size, and so on. The search interface which considers beam and column size, investigator, connection type, and so on, is shown in Figure 2.4(a), and a search result is shown in Figure 2.4(b). A typical report describing the details of a test, available from the database, is shown in Figure 2.4 (c).

2.2.2 PEER Structural Performance Database

The PEER structural performance database was developed at the University of Washington within the Pacific Earthquake Engineering Research Center (PEER) (http://nisee.berkeley.edu/spd, 2006). The database has been assembled to provide researchers with the data needed to evaluate and develop seismic performance models for reinforced concrete columns based on previously-conducted tests. There are results from 274 tests of rectangular-reinforced columns and 160 tests of spiral reinforced columns in the database. The test data in the database are organized by the column material properties, geometry, reinforcing details, test configuration, and so on. Figure 2.5(a) shows the search interface of the database which considers the column type, test configuration, failure type, and so on. Figure 2.5(b) shows a search result, and Figure 2.5(c) shows a typical report describing the details of a test, available from the database.

2.3 Review of Previous Work

This section reviews selected classes and attributes from the previous data models and considers the types of data that should be searchable in a structural database, based on the previously-developed databases.

2.3.1 Classes and Attributes of Existing Data Models for Structural Tests

The previous work on data models for structural tests provides insight into appropriate classes and attributes for the Lehigh Model. The selected classes and attributes (slots) of previous data models are presented in Tables 2.1, 2.2, and 2.3.

Table 2.1 shows that the Specimen class in the Reference NEESgrid Model includes the following attributes: Descriptions, Figures, and SensorSetup. Table 2.2 shows that the Specimen class in the Oregon State Model has the following attributes: specimenID, description, specimenFileURL, dataUsed, and so on. The Specimen class in both data models represents a test specimen using text descriptions and figures, however, this representation is too general and provides little potential for efficient searches on important specimen details, such as specimen components, material properties, geometry, and so on, which should be in the data model.

Table 2.2 shows that the Oregon State Model represents test equipment with the Equipment class, which includes the following attributes: equipmentID, equipmentClassID, description, siteSpecDBLocation (a location in the so-called "site specification database" where further details can be found), and so on. The NEEScentral Model represents test equipment in a similar way, using the Equipment Inventory class, except that sensors are represented in a separate class related to the Sensor Location Plan class. Equipment in the Reference NEESgrid Model is categorized into three classes, namely the primary equipment class, the secondary equipment class, and the tertiary equipment class. This way of grouping similar equipment with each equipment class having their own attributes provides more detailed information in the data model.

To represent the location of each component of an experiment, the Location class is included in the Reference NEESgrid Model (Table 2.1), which includes the attributes coordX, coordY, coordZ within a Cartesian coordinate system. Similar attributes are also included in the EquipmentConfiguration class of the Oregon State Model (Table 2.2). The NEEScentral Model provides a Coordinate Space class to represent the location of sensors. These location systems describe the equipment location in three dimensions. However, it is sometimes difficult to establish the precise coordinates of the components of an experiment in a laboratory, and the locations of the components are often described using drawings which provide relative locations.

The materials used to construct test specimens are important aspects of structural experiments that should be included in a data model. The NEEScentral Model provides a Material Property class, which is a generalization of the Concrete class, the Reinforcing Bar class, the Steel class and other classes. Inside each class, the attributes for the specific values of each material property are included. However, material properties of interest to researchers include both the nominal values (or the minimum specified values) and the actual values determined from material tests.

2.3.2 Searchable Fields in Existing Databases for Structural Tests

The existing databases for structural tests enable searches based on certain types of data to be conducted to retrieve selected data from the database. The “searchable fields” of these databases suggest the types of data that should be included in the Lehigh Model to enable information to be efficiently accessed.

The searchable fields of the SAC Design Information Database, shown in Table 2.4, include Beam Size, Column Size, Test ID, Lab, Sponsor, Investigator, FEMA 350 Type, and Connection Type. The searchable fields of the PEER Structural Performance Database, shown in Table 2.5, include Author, Column Type, Test Configuration, Span-to-Depth Ratio, Axial Load Ratio, Longitudinal Reinf Ratio, Failure Type, and Damage Observation. In both databases, the searchable fields at the less specific levels (e.g., Investigator or Author) are similar, however, the searchable fields at the more detailed levels are dependent on the characteristics of the tests included in the database.

A data model to support efficient access and use of structural test data would include many more searchable fields to enable researchers and practitioners to efficiently seek out the results of specific experiments. For example, each of the two databases summarized earlier are material dependent (i.e., one is for steel test specimens and the other is for reinforced concrete specimens), so the searchable fields do not include the material type. However, a more general data model for a variety of structural tests would include material type as a searchable field.

2.4 Summary

This chapter briefly summarized previous work on data models and databases for structural test data. The Reference NEESgrid Model, the Oregon State Model, and the more recent NEEScentral Model were briefly summarized and reviewed. Two existing databases, the SAC Design Information Database and the PEER Structural Performance Database, were summarized. These databases provide detailed information on structural tests and enable users to perform efficient searches to access test data. The classes and attributes of the data models were reviewed, and the specific searchable fields of the existing databases were reviewed. This summary and review provides the background for developing the Lehigh Model.

Table 2.1 Selected Classes and Attributes of Reference NEESgrid Model

Class	Slot	Value Type
Specimen	hasDescriptions hasFigures hasSensorSetup	DescriptiveFile VisualFile SensorSetup
PrimaryEquipment	shortDescription longDescription manufacturer operators hasFigures ---	String String String Person VisualFile ---
SecondaryEquipment	shortDescription longDescription owner manufacturer serialNumber hasFigures ---	String String Organization String String VisualFile ---
Location	name description coordX coordY coordZ locationMethod ---	String String Float Float Float String ---

Table 2.2 Selected Classes and Attributes of Oregon State Model

Class	Slot
Specimen	specimenID description specimenFileURL dateUsed dateRetired ---
Equipment	equipmentID equipmentClassID description siteSpecDBLocation ---
EquipmentConfiguration	configurationID equipmentID X0, X1 Y0, Y1 Z0, Z1 angle specimenID ---
Facility	facilityID shortDescription longDescription siteSpecDBLocation

Table 2.3 Selected Classes and Attributes of NEEScentral Model

Class	Slot
Experiment Setup	Models Material Properties Equipment Inventory Coordinate Spaces Sensor Location Plan ---
Model	CAD files
Material Property	Name Description Type (Concrete, Rebar, Soil-Clay, Soil-Sand, Steel) ---
Coordinate Space	Name Description Timestamp Multiplier Translation Rotation ---
Trial Setup	Input Motion Channel List
Facility	Host University Facility Name Department Laboratory Site URL Equipment List ---

Table 2.4 Searchable Fields in SAC Design Information Database

Searchable Field	Value Type or Choices of Value	
Beam Size	ANY, W14, W16, W18, W21, W24, W27, W30, W33, W36	exactly, or smaller, or bigger
Column Size	ANY, W12, W14, W16, W21, W24, W27, W30, W33, W36	exactly, or smaller, or bigger
Test ID	String	
Lab	String	
Sponsor	String	
Investigator	ALL, Anderson, Bjorhovde, Chen, --- (List of names)	
FEMA 350 Type	ALL, BB, BFB, BSEP, BUEP, DST, FF, RBS, SP, SW, WFP, WUF-B, WUF-W	
Connection Type	ALL, Pre-Northridge, PreNR-NT, PreNR-EndPl, PreNR-overlay, Cover Plate, End Plate, Free Flange, Flange Plate, Haunch, Pipe, Reduced Beam Section, Rib, Tree, Side Plate, Wing Plate, WSlot, WGap	

Table 2.5 Searchable Fields in PEER Structural Performance Database

Searchable Field	Value Type or Choices of Value
Author	String
Column Type	Rectangular, Spiral
Test Configuration	Cantilever, Cantilever with Hammer Head, Cantilever with Flexible Base, Double Cantilever, Double Ended
Span-to-Depth Ratio	Float
Axial Load Ratio	Float
Longitudinal Reinf Ratio	Float
Failure Type	Flexural, Shear, Flexural-Shear
Damage Observation	Concrete Crushing, Significant Spalling, Long Bar Buckling, Long Bar Fracture, Spiral Fracture, Loss of Axial Load Capacity

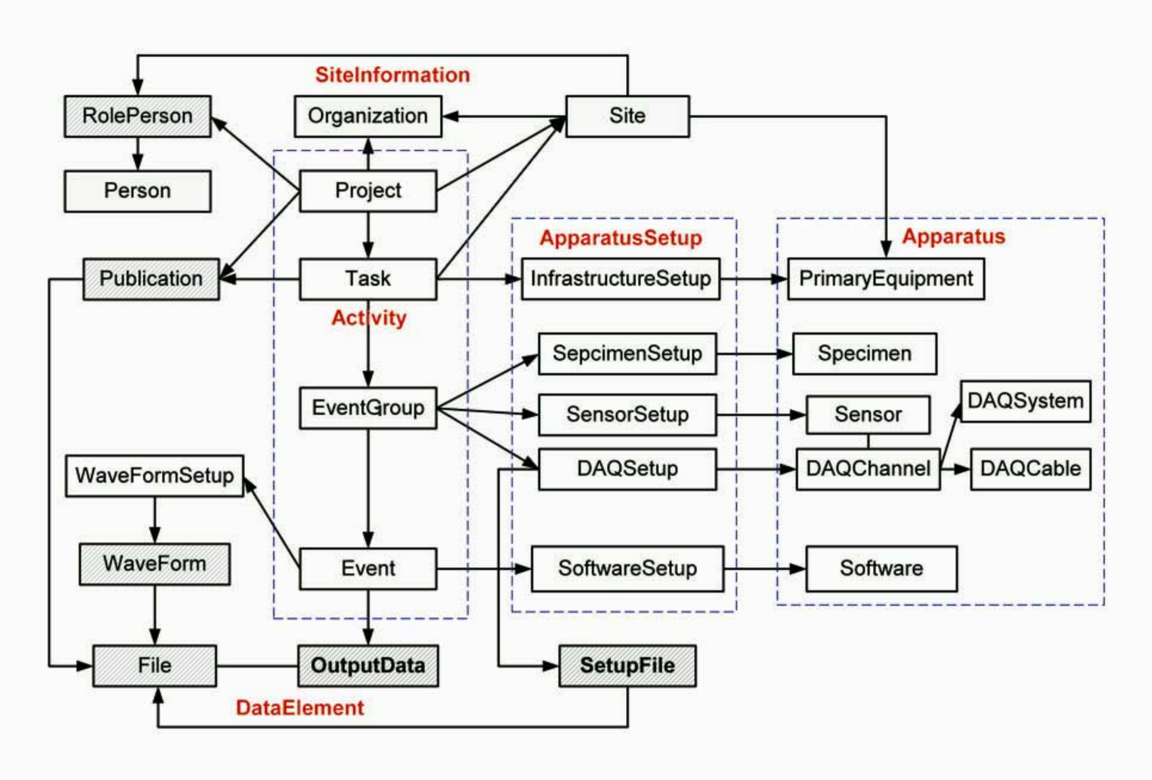


Figure 2.1 Reference NEESgrid Model (Peng and Law, 2004)

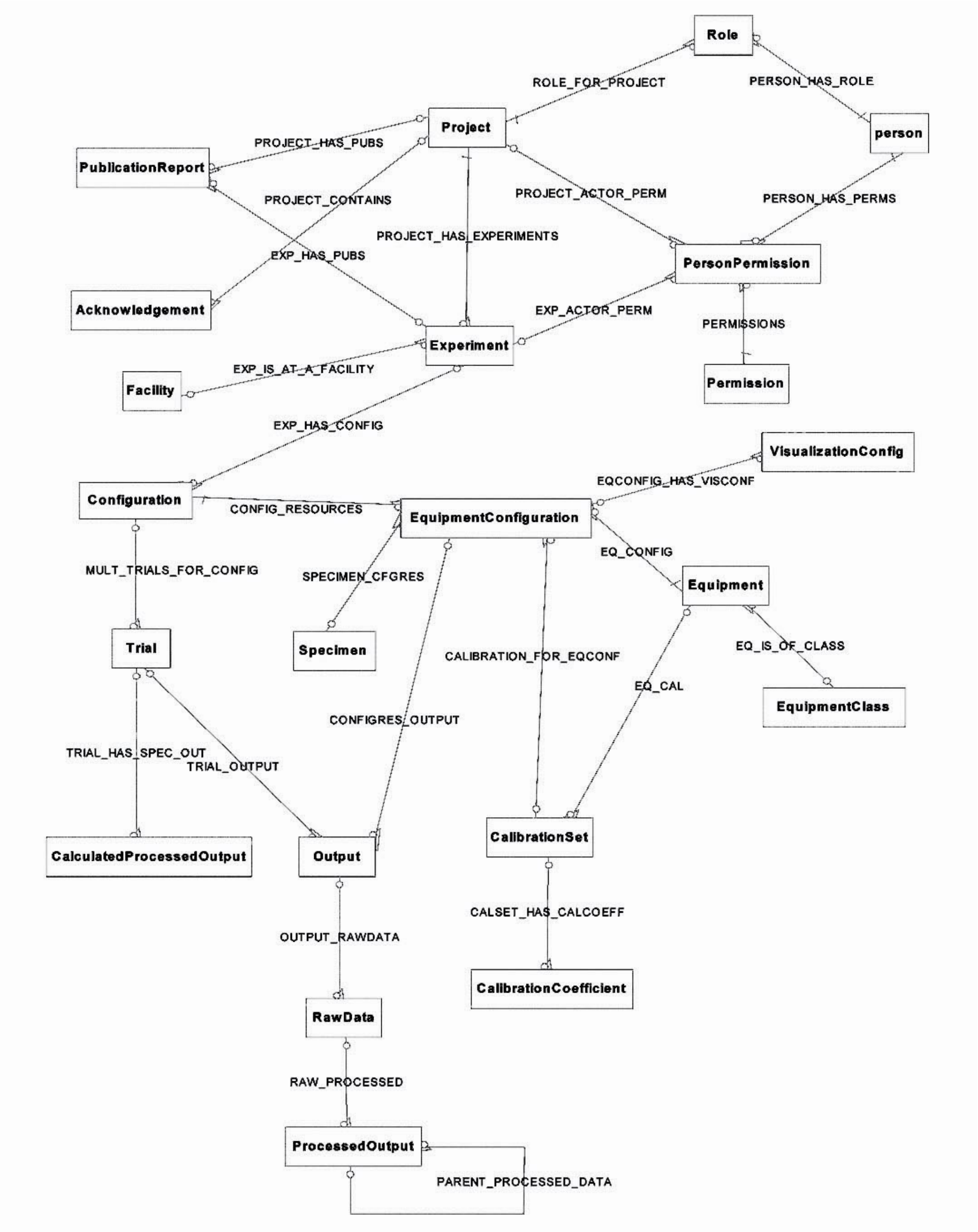


Figure 2.2 Oregon State Model (Oregon State University, 2003)

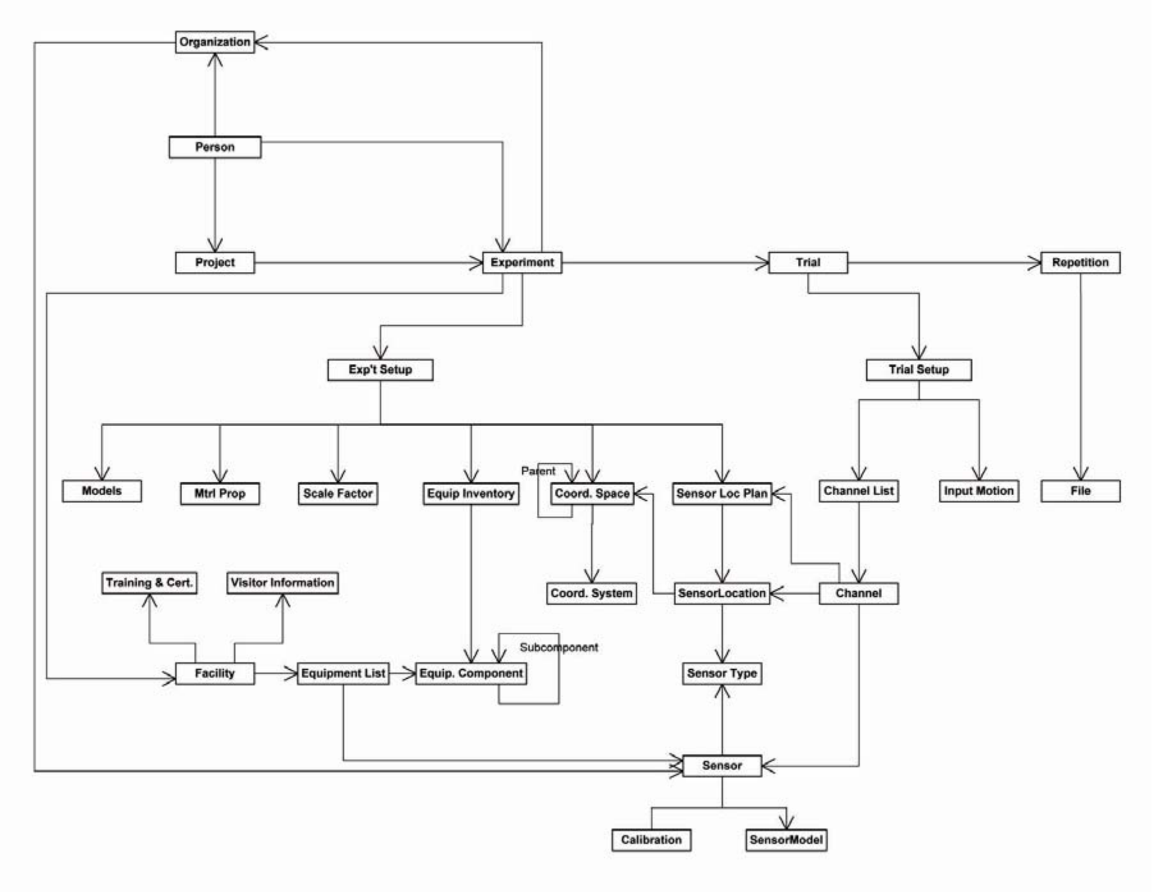
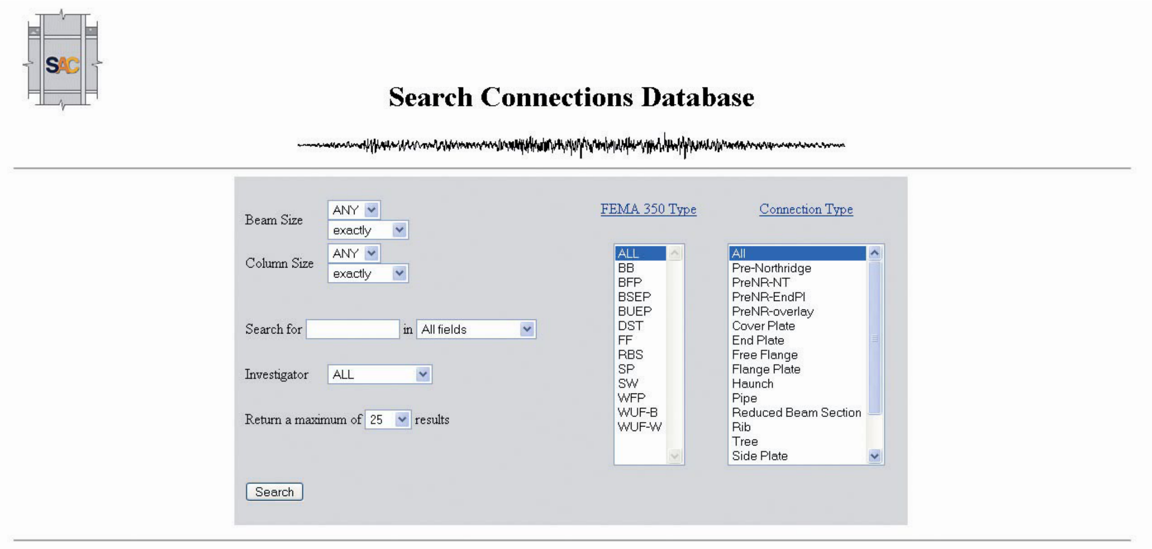


Figure 2.3 NEEScentral Model (NEESit, 2006)



Search Connections Database

Beam Size: ANY, exactly

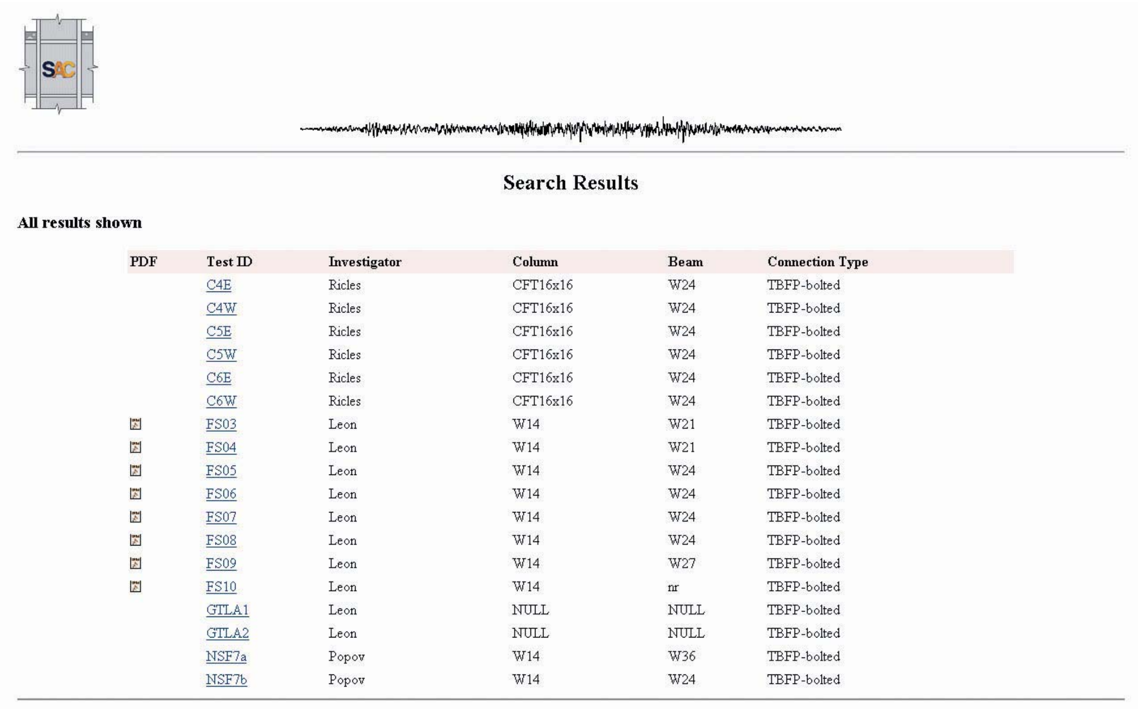
Column Size: ANY, exactly

Search for: in All fields

Investigator: ALL

Return a maximum of 25 results

(a)



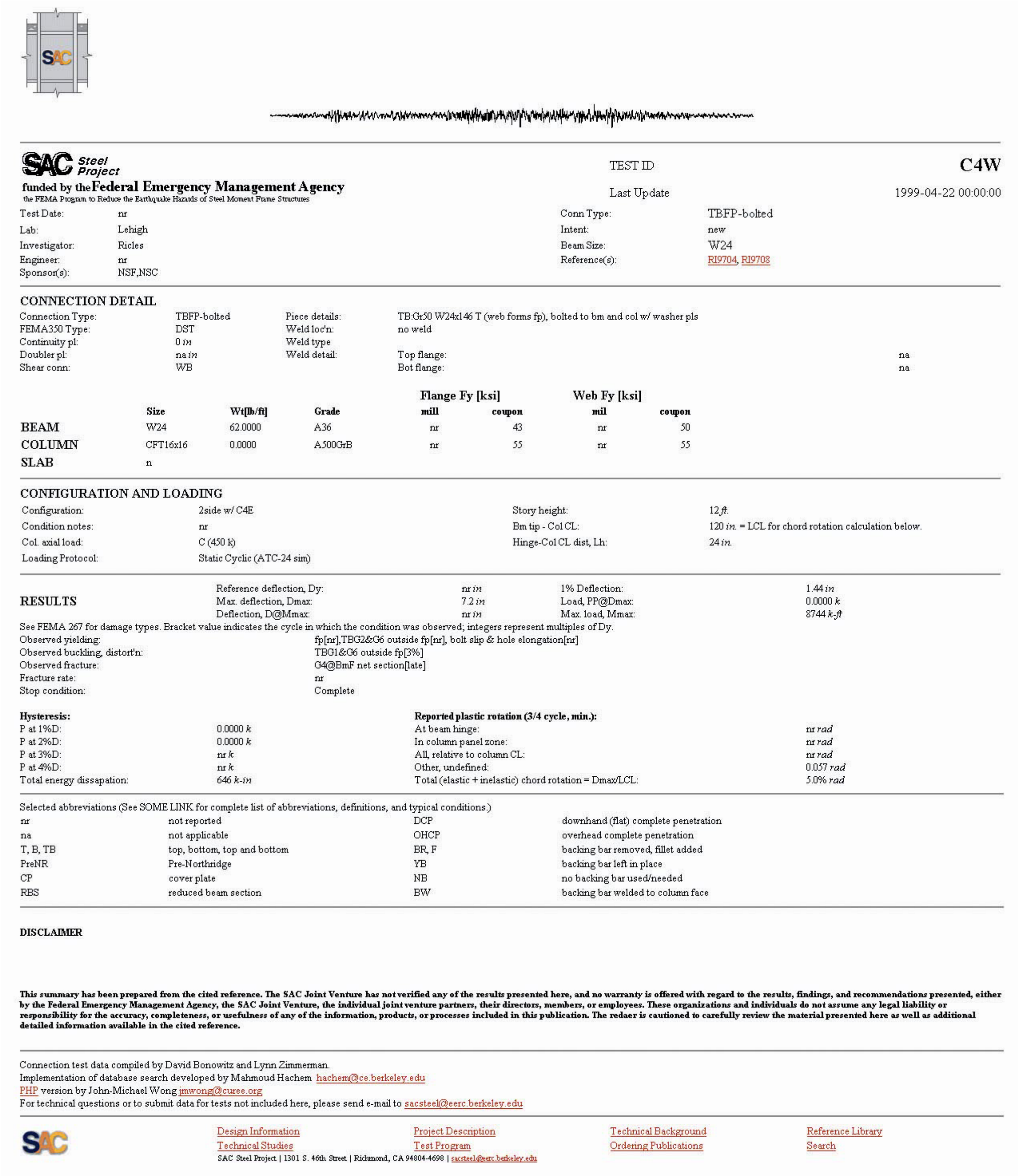
Search Results

All results shown

PDF	Test ID	Investigator	Column	Beam	Connection Type
	C4E	Ricles	CFT16x16	W24	TBFP-bolted
	C4W	Ricles	CFT16x16	W24	TBFP-bolted
	C5E	Ricles	CFT16x16	W24	TBFP-bolted
	C5W	Ricles	CFT16x16	W24	TBFP-bolted
	C6E	Ricles	CFT16x16	W24	TBFP-bolted
	C6W	Ricles	CFT16x16	W24	TBFP-bolted
📄	FS03	Leon	W14	W21	TBFP-bolted
📄	FS04	Leon	W14	W21	TBFP-bolted
📄	FS05	Leon	W14	W24	TBFP-bolted
📄	FS06	Leon	W14	W24	TBFP-bolted
📄	FS07	Leon	W14	W24	TBFP-bolted
📄	FS08	Leon	W14	W24	TBFP-bolted
📄	FS09	Leon	W14	W27	TBFP-bolted
📄	FS10	Leon	W14	nr	TBFP-bolted
	GTLA1	Leon	NULL	NULL	TBFP-bolted
	GTLA2	Leon	NULL	NULL	TBFP-bolted
	NSF7a	Popov	W14	W36	TBFP-bolted
	NSF7b	Popov	W14	W24	TBFP-bolted

(b)

Figure 2.4 SAC Design Information Database (http://www.sacsteel.org/, 2006)



SAC Steel Project
funded by the Federal Emergency Management Agency
the FEMA Program to Reduce the Earthquake Hazards of Steel Moment Frame Structures

TEST ID			**C4W**
Last Update			1999-04-22 00:00:00
Test Date:	nr	Conn Type:	TBFP-bolted
Lab:	Lehigh	Intent:	new
Investigator:	Ricles	Beam Size:	W24
Engineer:	nr	Reference(s):	RI9704, RI9708
Sponsor(s):	NSF,NSC		

CONNECTION DETAIL

Connection Type:	TBFP-bolted	Piece details:	TB:Gr50 W24x146 T (web forms fp), bolted to bm and col w/ washer pls	
FEMA350 Type:	DST	Weld loc'n:	no weld	
Continuity pl:	0 *in*	Weld type		
Doubler pl:	na *in*	Weld detail:	Top flange:	na
Shear conn:	WB		Bot flange:	na

				Flange Fy [ksi]		**Web Fy [ksi]**	
	Size	**Wt[lb/ft]**	**Grade**	**mill**	**coupon**	**mil**	**coupon**
BEAM	W24	62.0000	A36	nr	43	nr	50
COLUMN	CFT16x16	0.0000	A500GrB	nr	55	nr	55
SLAB	n						

CONFIGURATION AND LOADING

Configuration:	2side w/ C4E	Story height:	12 *ft.*
Condition notes:	nr	Bm tip - Col CL:	120 *in.* = LCL for chord rotation calculation below.
Col. axial load:	C (450 k)	Hinge-Col CL dist, Lh:	24 *in.*
Loading Protocol:	Static Cyclic (ATC-24 sim)		

RESULTS

Reference deflection, Dy:	nr *in*	1% Deflection:	1.44 *in*
Max. deflection, Dmax:	7.2 *in*	Load, PP@Dmax:	0.0000 *k*
Deflection, D@Mmax:	nr *in*	Max. load, Mmax:	8744 *k-ft*

See FEMA 267 for damage types. Bracket value indicates the cycle in which the condition was observed; integers represent multiples of Dy.

Observed yielding:	fp[nr],TBG2&G6 outside fp[nr], bolt slip & hole elongation[nr]
Observed buckling, distort'n:	TBG1&G6 outside fp[3%]
Observed fracture:	G4@BmF net section[late]
Fracture rate:	nr
Stop condition:	Complete

Hysteresis:		**Reported plastic rotation (3/4 cycle, min.):**	
P at 1%D:	0.0000 *k*	At beam hinge:	nr *rad*
P at 2%D:	0.0000 *k*	In column panel zone:	nr *rad*
P at 3%D:	nr *k*	All, relative to column CL:	nr *rad*
P at 4%D:	nr *k*	Other, undefined:	0.057 *rad*
Total energy dissapation:	646 *k-in*	Total (elastic + inelastic) chord rotation = Dmax/LCL:	5.0% *rad*

Selected abbreviations (See SOME LINK for complete list of abbreviations, definitions, and typical conditions.)

nr	not reported	DCP	downhand (flat) complete penetration
na	not applicable	OHCP	overhead complete penetration
T, B, TB	top, bottom, top and bottom	BR, F	backing bar removed, fillet added
PreNR	Pre-Northridge	YB	backing bar left in place
CP	cover plate	NB	no backing bar used/needed
RBS	reduced beam section	BW	backing bar welded to column face

DISCLAIMER

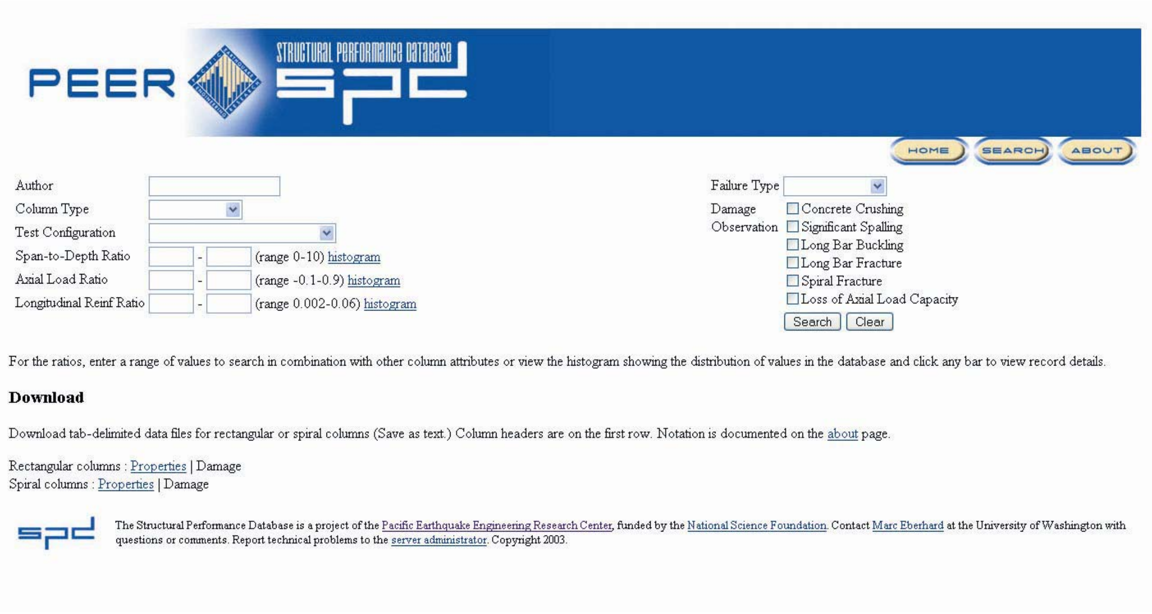
This summary has been prepared from the cited reference. The SAC Joint Venture has not verified any of the results presented here, and no warranty is offered with regard to the results, findings, and recommendations presented, either by the Federal Emergency Management Agency, the SAC Joint Venture, the individual joint venture partners, their directors, members, or employees. These organizations and individuals do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any of the information, products, or processes included in this publication. The redaer is cautioned to carefully review the material presented here as well as additional detailed information available in the cited reference.

Connection test data compiled by David Bonowitz and Lynn Zimmerman.
Implementation of database search developed by Mahmoud Hachem hachem@ce.berkeley.edu
PHP version by John-Michael Wong jmwong@curee.org
For technical questions or to submit data for tests not included here, please send e-mail to sacsteel@eerc.berkeley.edu

Design Information | Project Description | Technical Background | Reference Library
Technical Studies | Test Program | Ordering Publications | Search
SAC Steel Project | 1301 S. 46th Street | Richmond, CA 94804-4698 | sacsteel@eerc.berkeley.edu

(c)

Figure 2.4 SAC Design Information Database (continued)
(http://www.sacsteel.org/, 2006)



Author
Column Type
Test Configuration
Span-to-Depth Ratio - (range 0-10) histogram
Axial Load Ratio - (range -0.1-0.9) histogram
Longitudinal Reinf Ratio - (range 0.002-0.06) histogram

Failure Type
Damage Observation
☐ Concrete Crushing
☐ Significant Spalling
☐ Long Bar Buckling
☐ Long Bar Fracture
☐ Spiral Fracture
☐ Loss of Axial Load Capacity

For the ratios, enter a range of values to search in combination with other column attributes or view the histogram showing the distribution of values in the database and click any bar to view record details.

Download

Download tab-delimited data files for rectangular or spiral columns (Save as text.) Column headers are on the first row. Notation is documented on the about page.

Rectangular columns : Properties | Damage
Spiral columns : Properties | Damage

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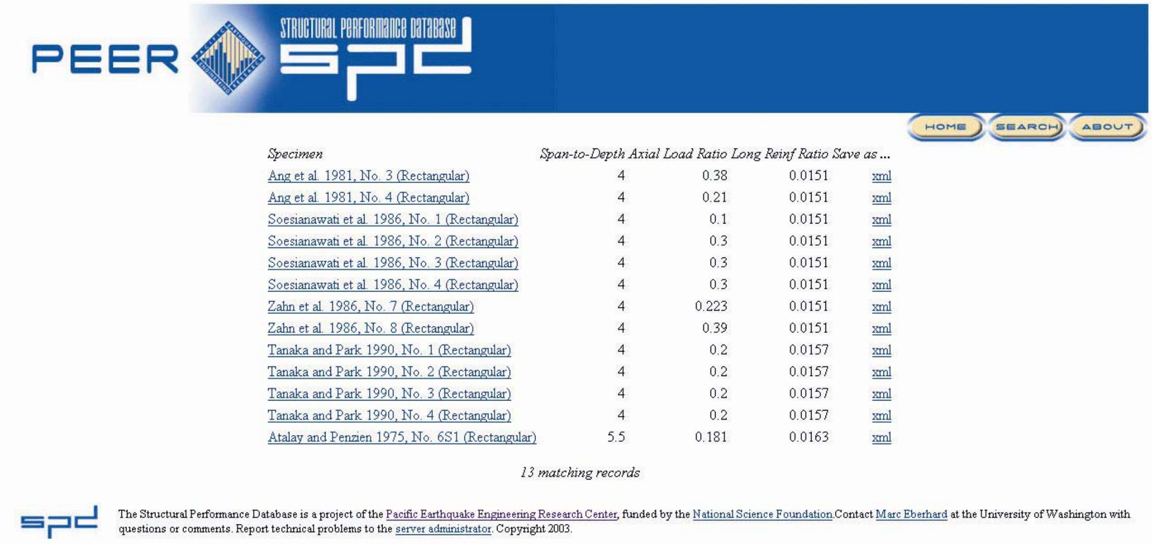
(a)



Specimen	*Span-to-Depth*	*Axial Load Ratio*	*Long Reinf Ratio*	*Save as ...*
Ang et al. 1981, No. 3 (Rectangular)	4	0.38	0.0151	xml
Ang et al. 1981, No. 4 (Rectangular)	4	0.21	0.0151	xml
Soesianawati et al. 1986, No. 1 (Rectangular)	4	0.1	0.0151	xml
Soesianawati et al. 1986, No. 2 (Rectangular)	4	0.3	0.0151	xml
Soesianawati et al. 1986, No. 3 (Rectangular)	4	0.3	0.0151	xml
Soesianawati et al. 1986, No. 4 (Rectangular)	4	0.3	0.0151	xml
Zahn et al. 1986, No. 7 (Rectangular)	4	0.223	0.0151	xml
Zahn et al. 1986, No. 8 (Rectangular)	4	0.39	0.0151	xml
Tanaka and Park 1990, No. 1 (Rectangular)	4	0.2	0.0157	xml
Tanaka and Park 1990, No. 2 (Rectangular)	4	0.2	0.0157	xml
Tanaka and Park 1990, No. 3 (Rectangular)	4	0.2	0.0157	xml
Tanaka and Park 1990, No. 4 (Rectangular)	4	0.2	0.0157	xml
Atalay and Penzien 1975, No. 6S1 (Rectangular)	5.5	0.181	0.0163	xml

13 matching records

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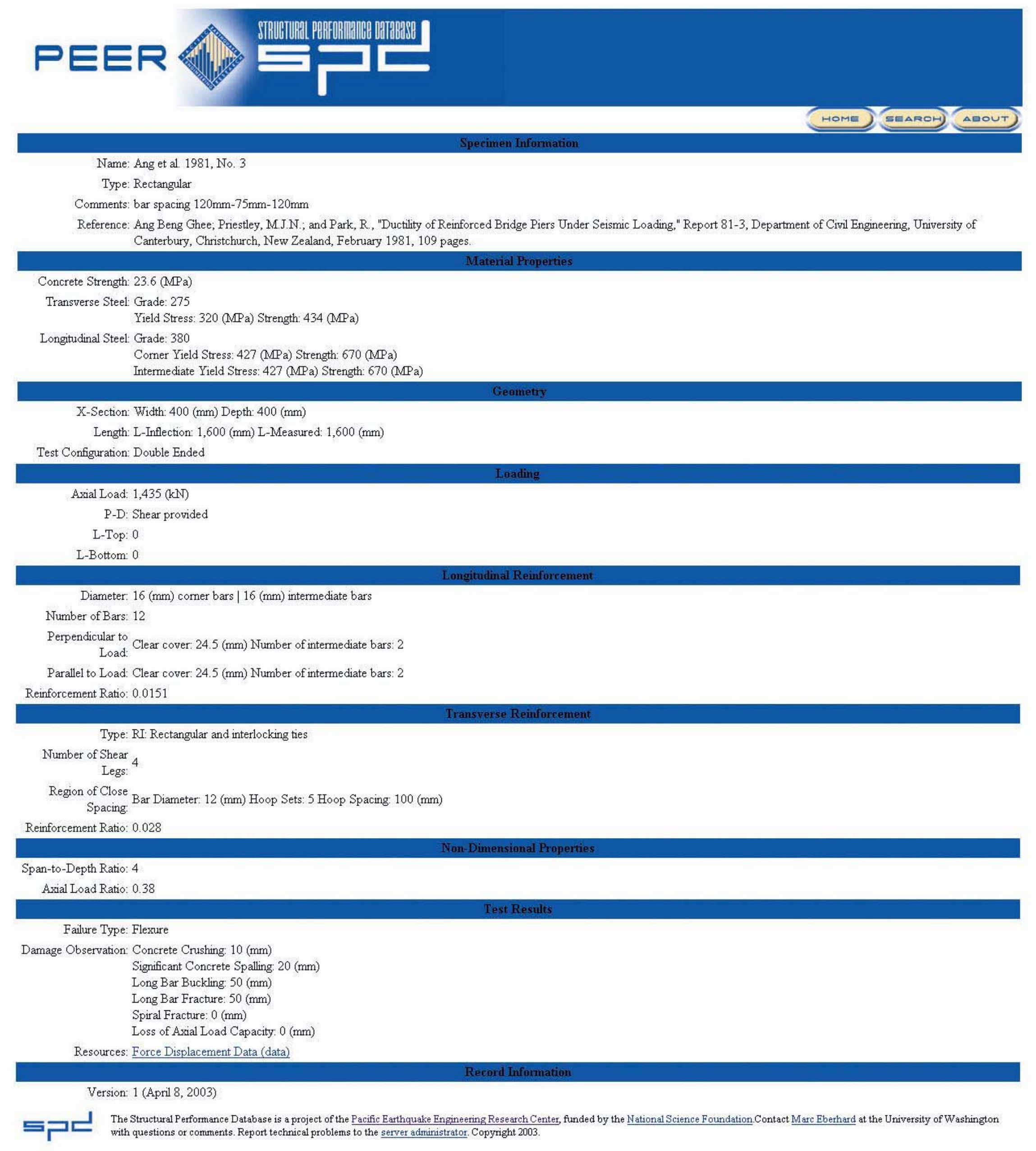
(b)

Figure 2.5 PEER Structural Performance Database (http://nisee.berkeley.edu/spd/, 2006)



Specimen Information

Name: Ang et al. 1981, No. 3
Type: Rectangular
Comments: bar spacing 120mm-75mm-120mm
Reference: Ang Beng Ghee; Priestley, M.J.N.; and Park, R., "Ductility of Reinforced Bridge Piers Under Seismic Loading," Report 81-3, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, February 1981, 109 pages.

Material Properties

Concrete Strength: 23.6 (MPa)
Transverse Steel: Grade: 275
Yield Stress: 320 (MPa) Strength: 434 (MPa)
Longitudinal Steel: Grade: 380
Corner Yield Stress: 427 (MPa) Strength: 670 (MPa)
Intermediate Yield Stress: 427 (MPa) Strength: 670 (MPa)

Geometry

X-Section: Width: 400 (mm) Depth: 400 (mm)
Length: L-Inflection: 1,600 (mm) L-Measured: 1,600 (mm)
Test Configuration: Double Ended

Loading

Axial Load: 1,435 (kN)
P-D: Shear provided
L-Top: 0
L-Bottom: 0

Longitudinal Reinforcement

Diameter: 16 (mm) corner bars | 16 (mm) intermediate bars
Number of Bars: 12
Perpendicular to Load: Clear cover: 24.5 (mm) Number of intermediate bars: 2
Parallel to Load: Clear cover: 24.5 (mm) Number of intermediate bars: 2
Reinforcement Ratio: 0.0151

Transverse Reinforcement

Type: RI: Rectangular and interlocking ties
Number of Shear Legs: 4
Region of Close Spacing: Bar Diameter: 12 (mm) Hoop Sets: 5 Hoop Spacing: 100 (mm)
Reinforcement Ratio: 0.028

Non-Dimensional Properties

Span-to-Depth Ratio: 4
Axial Load Ratio: 0.38

Test Results

Failure Type: Flexure
Damage Observation: Concrete Crushing: 10 (mm)
Significant Concrete Spalling: 20 (mm)
Long Bar Buckling: 50 (mm)
Long Bar Fracture: 50 (mm)
Spiral Fracture: 0 (mm)
Loss of Axial Load Capacity: 0 (mm)
Resources: Force Displacement Data (data)

Record Information

Version: 1 (April 8, 2003)

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Figure 2.5 PEER Structural Performance Database (continued) (http://nisee.berkeley.edu/spd/, 2006)

CHAPTER 3

FORMULATION OF LEHIGH MODEL

This chapter presents the formulation of the Lehigh Model for data associated with large-scale structural experiments. The main classes of the model and their relationships are discussed in this chapter. Details of the classes and attributes of the Lehigh Model are discussed in chapter 4.

3.1 Overview of Lehigh Model

Based on the previous work summarized in chapter 2 and studies of a number of experimental projects conducted at the ATLSS Center, the information related to structural experiments is classified into five main classes in the Lehigh Model as shown in Figure 3.1, namely, the project class, the experimental task class, the test condition class, the test class, and the data set class. The project class is at highest level and represents the overall research project which may include a number of experimental tasks, as well as analytical and other tasks. The experimental task class represents a single experimental task as might be described in a typical research proposal. Such a task may involve a number of experiments that require different types of test specimens and equipment, and may even require the use of more than one experimental facility. As discussed in chapter 4, the experimental task class is a generalization of two more specific classes, namely, the typical experimental task class and the hybrid experimental task class. An experimental task includes experiments conducted under one or more test conditions. The test condition class represents the specific set of conditions under which a structural experiment is conducted, including the test specimen, test fixtures, and so on. The test class represents a single test and produces a corresponding data set represented by the data set class. The relationships among these classes are shown in Figure 3.1. It shows that a project may have multiple experimental tasks, an experimental task may have multiple test conditions, a test condition may have multiple tests, and each test produces a unique data set.

3.2 Test Condition

This section focuses on the important aspects of a test condition, which defines the specific situation under which a structural experiment is conducted. The discussion of a test condition leads to the attributes of the test condition class, which were developed after studying a number of recent experimental projects conducted at the ATLSS Center.

3.2.1 Definition of Test Condition

A series of structural experiments often take place under a series of related but different test conditions. Often the related test conditions may be similar in many ways, but are different in certain details. As the series of experiments is conducted, the changes in experimental conditions (e.g., the test specimen, the test fixture, the instrumentation, the test protocol, etc.) will change the results. Figure 3.2 shows some examples of various combinations of test specimens, test facilities, test fixtures, instrumentation (sensors), and test protocols leading to different data sets. In the figure, Project 1 includes five experimental tasks, and each experiment task has a unique combination of test condition components leading to unique data sets.

Experimental Task 1 uses the same test specimen, test facility, test fixture, and instrumentation, but uses three different test protocols, leading to three data sets.

Experimental Task 2 uses the same test facility, test fixture, instrumentation and test protocol, but uses three different test specimens, leading to three data sets. It is not necessary for the three test specimens to be unique (independent of each other). The same structural assembly may be used repeatedly, with changes made to a detailed feature of the specimen, or with changes from damage accumulating from the series of experiments. Any change in the structural assembly results in a "new specimen" leading to a unique data set.

Experimental Task 3 uses the same test specimen, test fixture, instrumentation and test protocol, but uses three different test facilities, leading to three data sets.

Experimental Task 4 uses the same test specimen, test facility, instrumentation, and test protocol, but uses three different test fixtures, leading to three data sets. This example represents situations where the test fixture is modified or adjusted during the experimental task, perhaps to improve its performance (e.g., by reducing the friction, increasing the capacity, etc.).

Experimental Task 5 uses the same test specimen, test facility, test fixture, and test protocol, but uses different instrumentation, leading to three data sets. This example represents situations where sensors may be replaced, added, or relocated. Each arrangement of instrumentation (sensors) would lead to a unique data set.

The examples in Figure 3.2 can be represented as shown in Figure 3.3, where certain attributes of the test condition (specimen, facility, test fixture, sensors, and test protocol) are varied. In the figure, each vertical column of specimen, facility, test fixture, sensor, and test protocol corresponds to a unique test condition. Note that attributes are repeated between test conditions when they are unchanged.

3.2.2 Decomposition of Test Condition

Several example test conditions were shown above. The examples suggest that a test condition can be decomposed as shown in Figure 3.4, where the main components of a test condition are shown schematically. The main attributes of the test condition class correspond to these main components, and enable the Lehigh Model to represent these main components of a test condition. The main attributes are:

- Specimen: the specimen is a structural component, connection, or assembly that is the focus of a structural experiment.
- Facility: the facility is the laboratory where the structural experiment is conducted.
- Loading fixtures: the loading fixtures include hydraulic equipment and supporting structures used in the laboratory to generate loads on the specimen.
- Bracing and reaction fixtures: the bracing and reaction fixtures support the test specimen, maintaining the intended boundary conditions.
- Sensors: the sensors are instrumentation that measure the response of the specimen to loading.

- DAQ system: the DAQ system receives and records data representing the measurements from the sensors.
- Cables: the cables connect the sensors to the DAQ system.
- Tests: a test includes the test protocol (the specimen loading procedure) and the data set from the test. Each test produces a unique data set.

Figure 3.4 shows a test condition schematically as physical relationships among the specimen, facility, loading fixtures, bracing and reaction fixtures, sensors, DAQ system and cables, which are then related to a test. The test includes the test protocol and a resulting test data set. As shown later in chapter 4, the Lehigh Model uses the test condition class to represent a test condition. This class has attributes to represent the specimen, facility, loading fixtures, bracing and reaction fixtures, and so on.

The Lehigh Model uses the test class to represent a specific test. To avoid the redundancy of creating a new test condition each time a different test protocol is used, even though the specimen, facility, loading fixtures, bracing and reaction fixtures, and instrumentation remain unchanged, the test protocol attribute is included in the test class, and the notion of having one or more tests conducted under a single test condition is used in the model. As a result, Experimental Task 1 in Figures 3.2 and 3.3, would be represented as a single test condition with three tests, while Experimental Task 2, 3, 4, and 5 each would be represented as three test conditions with each test condition having a single test.

3.2.3 Comparison of Data Model Terminology

The terminology used to describe attributes in the Lehigh Model is compared with other data model terminology in Table 3.1. “specimen” is used in the Lehigh Model, Reference NEESgird Model, and Oregon State Model, but not in the NEEScentral Model which uses “model” to describe the specimen. Test equipment is decomposed into “loading fixtures”, “bracing and reaction fixtures”, “sensors” and so on in the Lehigh Model, while the other models use more general terminology to describe these attributes. “test protocol” is used in the Lehigh Model to describe the specimen loading procedure used in a structural experiment. The other models use different terminology.

3.3 Summary

This chapter discusses the formulation of the Lehigh Model. An overview of the model is given in terms of the main classes, namely the project class, the experimental task class, the test condition class, the test class, and the data set class. Special attention is given to identifying and organizing the attributes of a test condition, which defines the specific situation under which a structural experiment is conducted. The identification and organization of these attributes leads directly to the important test condition class and the related attributes and classes, which are presented in more detail in chapter 4.

Table 3.1 Comparison of Data Model Terminology

	Lehigh Model	**Reference NEESgrid Model**	**Oregon State Model**	**NEEScentral Model**
1	Specimen	Apparatus ▪ Specimen ▪ Primary Equipment (infrastructure) ▪ Secondary Equipment (sensor, DAQ system, DAQ channel, DAQ cable) ▪ Tertiary Equipment	Specimen	Models
2	Facility		Facility	Facility
3	Loading Fixtures		Equipment	Equipment Inventory, Sensor
4	Bracing and Reaction Fixtures			
5	Sensors			
6	Cables			
7	DAQ Systems			
8	Test Protocol	Software Setup	N/A	Input Motion
9	Data Set (raw data, processed data)	Output Data	Output, Raw Data, Processed Data	Unprocessed Data, Converted Data, Corrected Data, Derived Data

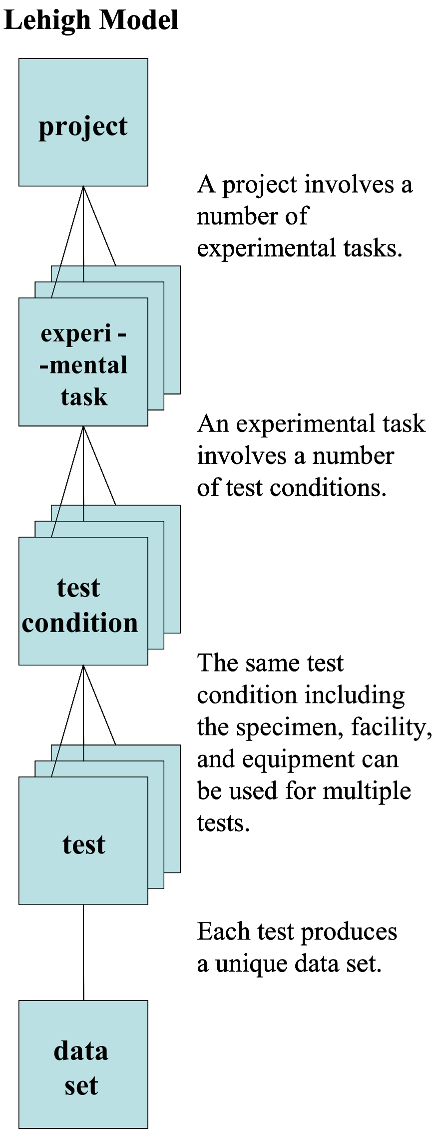


Figure 3.1 Class Hierarchy of Lehigh Model

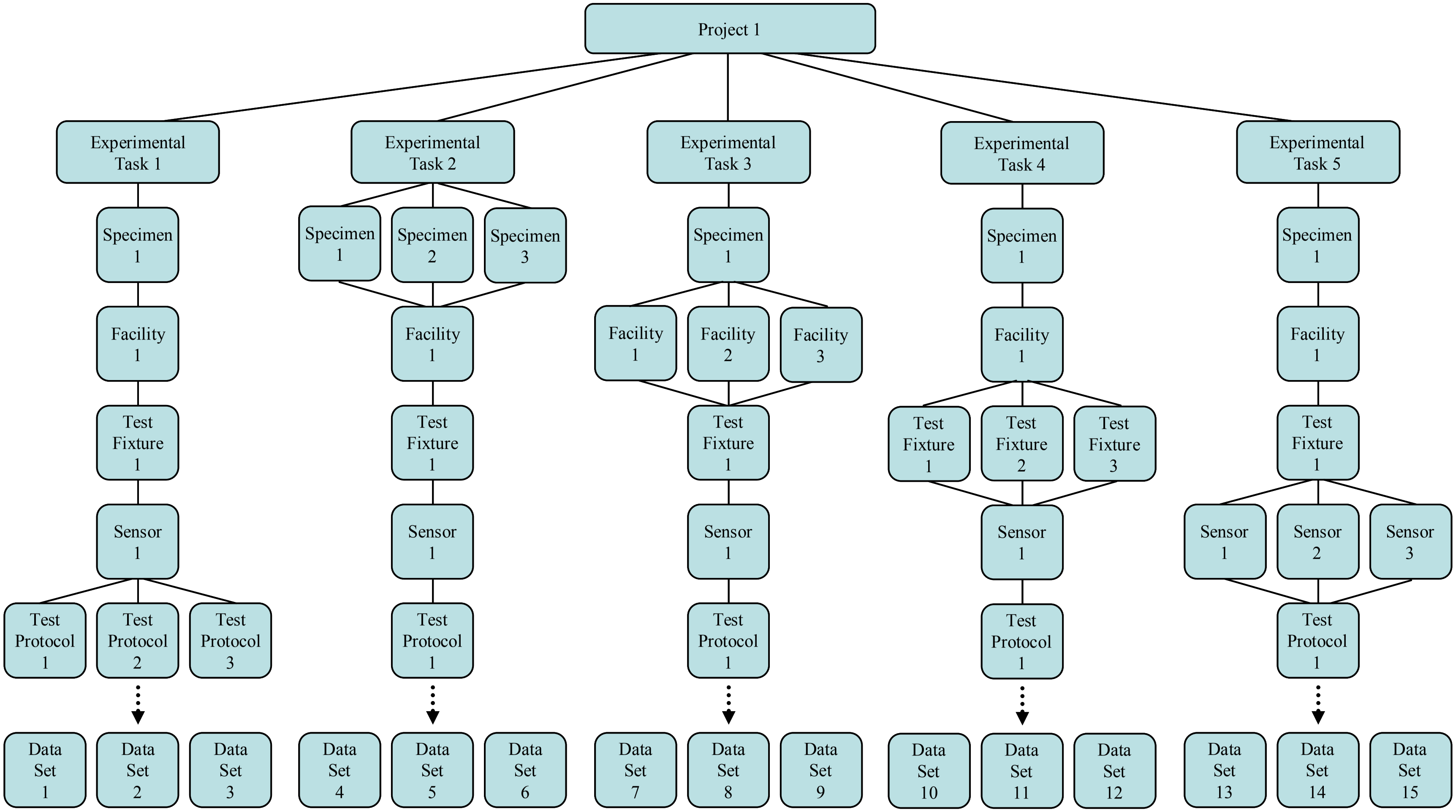


Figure 3.2 Example Experimental Tasks

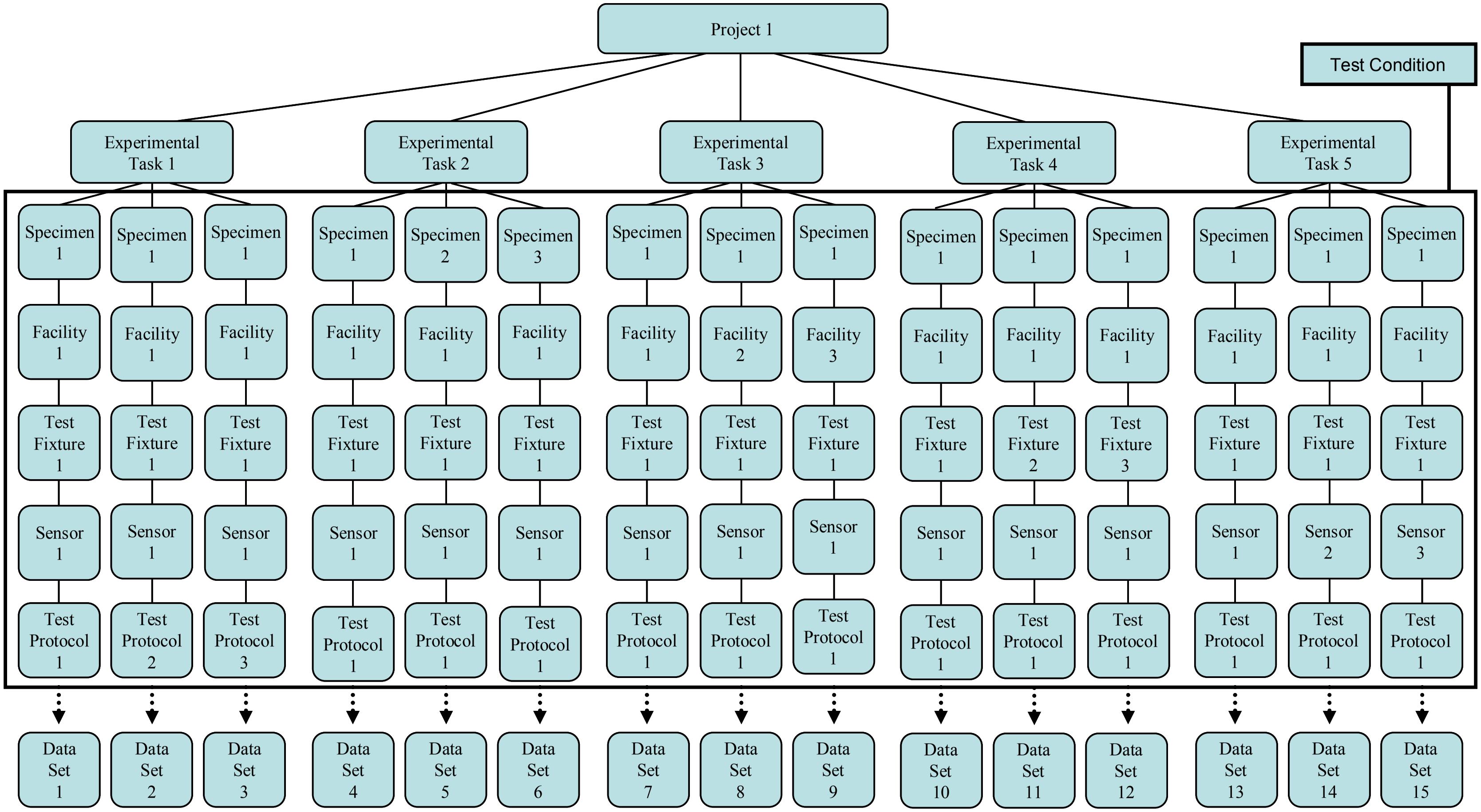


Figure 3.2 Attributes of Test Condition Class for Example Experimental Tasks

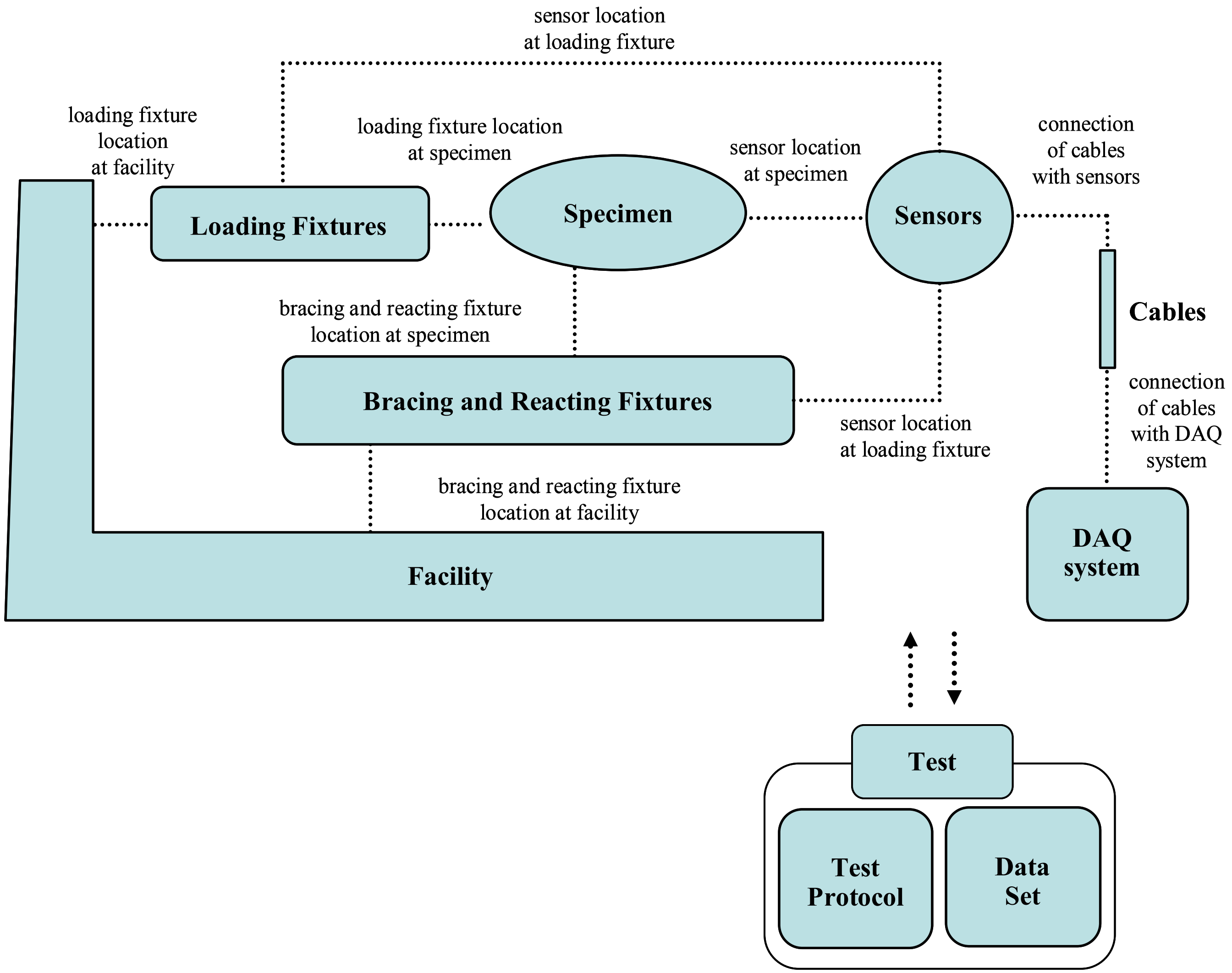


Figure 3.4 Decomposition of Test Condition

CHAPTER 4

CLASSES AND ATTRIBUTES OF LEHIGH MODEL

This chapter describes the classes and attributes of the Lehigh Model using the concepts developed in chapter 3. In this chapter, section 4.1 explains the notation used for the classes and attributes of the Lehigh Model, and section 4.2 gives an overview of the class hierarchy. The details of the classes and attributes are described in section 4.3. Section 4.4 compares the main classes and attributes of the Lehigh Model with those of other data models. Section 4.5 provides a summary.

4.1 Notation for Classes and Attributes of Lehigh Model

The classes and attributes of the Lehigh Model shown in Figure 4.1 and other figures of this chapter are represented using a modified entity-relationship diagram developed for entity-based integrated product and process models (Hong and Sause, 1994). Each rectangle in the figure indicates an entity category (referred to as a class). Each attribute of the class is shown below the rectangle with a horizontal bar. If the attribute is single-valued, the bar ends with an empty circle, and if the attribute is multi-valued, the bar ends with a black circle. The value set of an attribute (the set of possible values for the attribute) is represented in square brackets. The attribute type is identified in parentheses. The attribute of a class is classified into two main types: (1) "data-valued" attributes (DVA) whose values are alphanumeric or are otherwise indecomposable; and (2) "object entity-valued" attributes (OEVA) whose values refer to other classes. Further classifications of the attributes include based attributes (B), internally derived attributes (DI), and externally derived attributes (DE). Some of these attribute types are used in the figures of this chapter.

4.2 Levels of Classes in Class Hierarchies of Lehigh Model

The Lehigh Model includes a number of classes resulting in a class hierarchy. Figure 4.1 shows the four levels of classes in the class hierarchy. Some of the classes and the attributes at each level are shown in the figure.

The project class in Figure 4.1 includes the experimental tasks attribute and the analysis tasks attribute. The attributes are multi-valued and they represent multiple numbers of experiment tasks and analysis tasks, respectively. The value set of the experimental tasks attribute refers to the experimental task class which is a generalization of the typical experimental task class and the hybrid experimental task class. The typical experimental task class represents a typical structural experimental task, such as a pseudo-static or a pseudo-dynamic experiment. The hybrid experimental task class represents research tasks involving hybrid pseudo-dynamic experiments.

The typical experimental task class includes a multi-valued attribute to represent a number of test conditions. The test condition class includes the attributes for the specimen, facility, loading fixture, and bracing and reaction fixture. A specimen, a facility, a number of loading fixtures, and a number of bracing and reaction fixtures define a test condition. If any of these elements changes then the test condition is different. The test condition class also includes multi-valued attributes for tests and analyses. For a given test condition, a number of tests and a number of analyses of the test specimen under the given test condition might be performed. The test class includes attributes for the test protocol defining the loading protocol, the uncontrolled test conditions such as uncontrolled temperatures and other environmental conditions, and the data set from a test including the generated raw data and other data.

The hybrid experimental task class includes attributes for a simulation coordinator, a number of analytical substructures, and a number of physical substructures. In hybrid experiments, the physical substructures are the parts of a structure tested in the laboratory, so the physical substructure class is similar to the test condition class. Similarly, the physical substructure test class is similar to the test class. However, there are some differences because the tests of a physical substructure are controlled by the simulation coordinator. The differences are discussed in the following section.

4.3 Classes and Attributes of Lehigh Model

The classes and attributes shown in Figure 4.1 and other related classes and attributes are described in detail in this section. The classes and attributes at the higher levels are presented first and are followed by the classes and attributes at lower levels.

4.3.1 Project and Experimental Task Classes

The project and experimental task classes at the two highest levels shown in Figure 4.1 are shown in detail on the left in Figure 4.2. The project class includes the description attribute and the multi-valued descriptive files attribute as well as the attributes for experimental tasks and analysis tasks as explained in the previous section. The description attribute of the project class describes briefly the project, and the descriptive files attribute includes multiple files describing the project.

The experimental task class also includes the description attribute and the descriptive files attribute. The description attribute of the experimental task class describes briefly the experimental task, and the descriptive files attribute includes multiple files describing the experimental task. The use of these attributes is similar in many classes of the Lehigh Model. When a class includes the description attribute and the descriptive files attribute, the description attribute describes briefly the object from the class, and the descriptive files attribute includes multiple files describing the object from the class.

The experimental task class also includes attributes for organizations, publications, and presentations related to the experimental task. Since the experimental task class is a generalization of the typical experimental task class and the hybrid experimental task class, the five attributes of the experimental class are common attributes of the typical experimental class and the hybrid experimental task class, and are inherited by these two classes. The typical experimental task class includes the attribute for test conditions and the hybrid experimental task class includes the attributes for a simulation coordinator, a number of analytical substructures, and a number of physical substructures.

In hybrid experiments, the physical substructures are the parts of the structure tested in the laboratory, so the physical substructures attribute of the hybrid experimental task class is similar to the test conditions attribute of the typical experimental task class. The value sets of the test conditions attributes and the physical substructures attribute refer to the similar classes that are the test condition class and the physical substructure classes, which are shown near the bottom of Figure 4.2 and are described in the following section.

4.3.2 Test Condition Classes

The abstract test condition class shown in Figure 4.2 is an abstract class of the test condition class and physical substructure class, which are value sets for attributes of a typical experimental task and a hybrid experimental task, respectively. The abstract test condition class is “abstract” because objects from this class are not used in the model. The purpose of this class is to represent attributes that are common attributes of the test condition class and the physical substructure class, which are inherited by the two classes. The description and descriptive files attributes of the abstract test condition class describe the test conditions. The setup drawings and photos attribute includes the drawing files for the overall setup of the tests. The specimen attribute, the facility attribute and other attributes up to and including the simulation systems attribute describe the setup of the tests. For the given setup, a number of tests can be performed. A number of analyses of the test specimen can be also performed since the analyses attribute is included in the abstract test condition class. The value sets of the attributes of the abstract test condition class, the test condition class, and the physical substructure class refer to other classes such as the specimen class and the facility class, which are described in the following sections.

4.3.2.1 Specimen Class

The specimen class in Figure 4.3 describes the specimen used in a test condition. The specimen class in Figure 4.3 includes the specimen drawings and photos attribute and the specimen components attribute. The specimen drawings and photos attribute includes the drawing and photo files for the specimen, while the setup drawings and photos attribute of the abstract test condition class shown in Figure 4.2 includes the drawing and photo files for the overall test setup. For a small scale experiment, the setup drawing and photo files can include all the drawing and photo files for the test. However, for a large scale experiment, the specimen drawings and photos attribute will include more detailed drawing and photo files for the specimen. The specimen component attribute of the specimen class in Figure 4.3 describes the components that comprise the specimen. The number of components for a specimen depends on the scale and complexity of the specimen and on the importance of the components. Some specimens may have only a few components, and others may have many components.

The specimen component class in Figure 4.3 includes attributes for the geometry and materials of the specimen. These are described in the more detailed classes in the figure. The geometry class describes the geometry of a specimen component. The geometry class includes the drawings and photos attribute which includes drawing and photo files for the specimen component. The material class was modified from the material property class of the NEEScentral Model (NEESit, 2006). The material class in the figure includes the material property value class at its lower level. The material property value class generalizes the nominal value class and the actual value class. The actual value class includes the attributes for a number of the test values and the average value. The location attribute of the specimen component class are used for the describing the location of a specimen component at a facility. The value set of this attribute refers to the location class (not shown in the figure, but shown in a later figure). Since the description of the locations of the specimen components in a facility require the description of the facility, the location class will be presented after describing the facility class.

4.3.2.2 Facility Class

Figure 4.4 shows the facility class which is the value set of an attribute of the test condition shown in Figure 4.2. The facility class in Figure 4.4 describes the facility where the tests are performed. The specifications attribute of the facility class describes the information on the specifications of the facility, which may be retrieved from a database. Figure 4.5 shows how this information or data can be retrieved from databases. A central database such as the NEES Site Specification Database includes information on the facilities and major equipment of all universities related to the NEES program, and the database at Lehigh University includes the information on the facility and major equipment of Lehigh University. This information can be extracted from these databases into the Lehigh Model.

The facility class in Figure 4.4 includes the attributes used for describing locations of specimen components and equipments. The origin of the coordinate systems attribute describes the origin in the facility. The axes defined by the origin become the global axes for describing the locations. Figure 4.6a shows the global axes for the facility at the ATLSS Center at Lehigh University. Two dimensional reference planes can be defined (Figures 4.6b and 4.6c) in the space defined by the global axes. The defined reference planes will be the planes where the locations of specimen components and equipments are described. The facility class in Figure 4.4 includes the attributes for all reference planes and the reference planes for the strong floor and reaction walls.

Locations in Facility

After the three dimensional space and the reference planes are defined in the facility class shown in Figure 4.5, the locations of the specimen components and equipment can be described. Figure 4.7 shows the location class and its lower level classes. The location class is a generalization of the location using drawings class and the location using location points and lines class. This arrangement of classes shows that a location can be described using drawing files or using the concepts of location points and lines. These concepts are represented by the location using location points and lines class in Figure 4.7 and in the classes shown in Figures 4.8 and 4.9, and are illustrated in Figure 4.10.

Figure 4.10 shows how location points and lines are defined and used for describing the locations of specimen components and equipment. Two location points for an actuator, and two locations lines and one location point for a beam or a column are described in Figure 4.10a, and then the locations of the location points and lines in elevation or in floor plan are described in Figures 4.10b and 4.10c in order to describe the locations the actuator and the beam or the column.

Since the locations of specimen components and equipment are described by describing the locations of the location points and lines, the location using location points and lines class in Figure 4.7 includes these attributes. The value sets of these attributes refer to more detailed classes, which are the location point and its location class and the location line and its location class. These two classes include the attributes for the locations of location points and lines whose value sets refer to the reference point class and the reference line class. The reference point class is a generalization of the reference point in reference plane class and the reference point in 3D space class to allow the reference point to be described in a reference plane (Figure 4.8a) or in 3D space (Figure 4.9a). Similarly, the reference line class in Figure 4.7 is a generalization of the reference line in reference plane class and the reference line in 3D space to allow the reference line to be described in a reference plane (Figure 4.8b) or in 3D space (Figure 4.9b).

4.3.2.3 Loading Fixture and Bracing and Reaction Fixture Classes

Figure 4.11 shows the loading fixture class and the bracing and reaction fixture class which are value sets of attributes of the test condition class shown in Figure 4.2. The loading fixture class in Figure 4.11 describes the equipment for loading a specimen. The loading fixture class generalizes the actuator class and the other loading fixture class, showing that loading fixtures are classified into actuators and other loading fixtures because they usually require separate descriptions. The specifications for an actuator can be extracted from a database, but the properties of other loading fixtures are not in a database and need to be described. The location of an actuator requires the description of the actuator-fixed-node (AFN) and the actuator-structure-node (ASN) (Mercan et al, 2006). The attributes for these two nodes are included in the actuator class in the Figure 4.11. The other loading fixture class includes the geometry, material, and location attributes. The bracing and reaction fixture class describes the equipments used for supporting a specimen. Since the bracing and reaction fixtures are described rather simply compared with the loading fixtures, the bracing and reaction fixture class includes two attributes for a description and for drawing and photo files.

4.3.2.4 Classes for Data Acquisition and Test Control

Figure 4.12 shows classes to represent data acquisition and test control equipment for structural experiments. These classes are value sets of attributes of the test condition class shown in Figure 4.2. The sensor class in Figure 4.12 describes a physical device that measures a structural response. Examples of sensors are a load cell, a displacement transducer, a rotation meter, and a strain gage. The specifications of a sensor are from a database. The information on the location and the calibration are included in the sensor class. The cable class describes a cable which connects a sensor and a Data Acquisition (DAQ) system. The DAQ system class describes the DAQ hardware that receives and records data. The specifications of a DAQ system are from a database. The controller system and simulation system classes are used to describe the systems for controlling tests.

4.3.2.5 Test and Analysis Classes

Figure 4.13 shows the test and analysis classes which are value sets of attributes of the test condition class shown in Figure 4.2. As described earlier, the abstract test condition class in Figure 4.2 is a generalization of the test condition class and the physical substructure class, and the attributes of the abstract test condition class are inherited by these two classes. For a given test condition including the specimen, facility, and fixtures, multiple tests and analyses can be performed. The test class in Figure 4.13 describes a test which is defined by a test protocol and generates a data set. The test protocol class includes the history file and simulation method files attributes, and the data set class includes the attributes for numerical and visual data. The test class also includes the uncontrolled test conditions attribute to describe other test conditions which are not controlled but may affect the test data. Uncontrolled temperature is an example of an uncontrolled test condition. The analysis class in the figure describes an analysis performed under the given test condition, and includes the attributes of the software, input code, and analysis results.

4.3.3 Hybrid Experimental Task Class

The classes for hybrid experimental tasks are shown in Figure 4.14. The hybrid experimental task class, also shown in Figure 4.2, is a specialized class of the experimental task class. The hybrid experimental task class shown in Figure 4.2 includes the attributes for a simulation coordinator, a number of analytical substructures, and a number of physical substructures to represent structural experiments using the substructuring technique (Dermitzakis and Mahin, 1985). In a hybrid experiment, the physical substructures are loaded using the commands generated by the simulation coordinator. The results from the substructures are used as feedback to the simulation coordinator to be used as input to the overall simulation model controlled by the simulation coordinator. The analytical substructures also receive commands from and provide feedback to the simulation coordinator, similar to the physical substructures. These communications among the simulation coordinator, the analytical substructures, and the physical substructures are represented in the classes and attributes in Figure 4.14.

Figure 4.14 shows the simulation coordinator class, the analytical substructure class, the physical substructure class, and the other related classes. The three classes include the attributes for the facility information. The simulation coordinator class includes the simulation coordinator facility attribute, the analytical substructure class includes the analytical substructure facility attribute, and the physical substructure class includes the facility attribute inherited from the abstract test condition class shown in Figure 4.2. These attributes allow distributed hybrid experiments with the simulation coordinator, the analytical substructures, and the physical substructures at different facilities to be represented.

The simulation coordinator class, the analytical substructure class, and the physical substructure class in Figure 4.14 include multi-valued attributes for a number of simulations, a number of analytical substructure computations, and a number of physical substructure tests. To relate an individual simulation with the corresponding analytical substructure computations and physical substructure tests, and also to capture the commands and feedback, the simulation class includes the multi-valued substructure interfaces attribute. The value set of the substructure interfaces attribute refers to the simulation substructure interface class which is a generalization of the analytical substructure interface class and the physical substructure interface class. The analytical substructure computation class and the physical substructure test class also include an attribute whose value set refers to the simulation substructure interface class.

Figure 4.14 has shown the main classes and attributes for hybrid experimental tasks. The other classes and attributes are being developed by current research.

4.4 Comparison of Data Models for Structural Tests

The classes and attributes of the Lehigh Model have been described in the earlier section. This section compares the class hierarchies of the Lehigh Model with those of other data models for structural tests.

4.4.1 Class Hierarchies of Data Models

Figure 4.15 compares the Lehigh Model with the NEEScentral Model (NEESit, 2006), the Stanford Model (the Reference NEESgrid Model, Peng and Law, 2004), and the Oregon State Model (Oregon State University, 2003). The same notation is used to represent the main classes and attributes of the data models. Brief explanations for each data model are as follows:

(1) Lehigh Model (Figure 4.15a): A project includes multiple experimental tasks and analysis tasks. An experimental task may be a typical experimental task or a hybrid experimental task. Each typical experimental task includes a number of test conditions. For a test condition, multiple tests and analyses can be performed. Each test includes the attributes for the test protocol, uncontrolled test conditions, and a data set.

(2) NEEScentral Model (Figure 4.15b): A project includes a number of experiments (or simulations). Each experiment has its own experimental setup and includes a number of trials. Each trial has different input and generates a number of test data sets.

(3) Stanford Model (Figure 4.15c): A project includes a number of tasks which can be single site tasks or multi-site tasks. For the same infrastructure, a number of event groups can be performed. Each event group has its own setup and includes a number of events. Each event has its own software setup and output data.

(4) Oregon State Model (Figure 4.15d): A project includes a number of experiments. An experiment is carried out at a facility and has a number of configurations. Each configuration has its own equipment configuration and a number of trials which include the output.

4.4.2 Comparison of Classes Hierarchies of Data Models

The data models shown in Figures 4.15a to 4.15d have levels of class hierarchies from the top level classes to the lower level classes. When the lowest level classes are considered to be the classes that include the test data, the main classes of the data models are as follows:

(1) Lehigh Model: project – experimental task – test condition – test.

(2) NEEScentral Model: project – experiment or simulation – trial or run.
(3) Stanford Model: project – task – event group – event.
(4) Oregon State Model: project – experiment – configuration – trial.

For all four data models, the project class is the top level class. Each model uses different definitions of the lower level classes. The Lehigh Model defines the experimental task class which includes a number of test conditions. The NEEScentral Model, the Stanford Model and the Oregon State Model define experiments or tasks related to specific organizations or facilities. The test condition class in the Lehigh Model includes the attributes for the setup of the specimen and equipment. The test condition class corresponds to the experiment or simulation class in the NEEScentral Model, the event group class in the Stanford Model, and the configuration class in the Oregon State Model. The test class in the Lehigh Model is similar to the trial or run class in the NEEScentral Model and the event class in the Stanford Model.

4.5 Summary

This chapter has described the classes and attributes of the Lehigh Model, and has compared this model with other data models. The Lehigh Model has a class hierarchy consisting of the project, experimental task, test condition, and test classes to organize information related to structural experiments. The project class includes the experimental tasks and analysis tasks attributes. The experimental task class generalizes the typical experimental task and hybrid experimental task classes. The test condition class includes attributes for describing test conditions, such as the specimen, facility, and loading fixtures. The test class includes attributes for the test protocol, uncontrolled test conditions, and data set. The following chapter presents an application of the classes and attributes of the Lehigh Model using steel frame connection tests as an example.

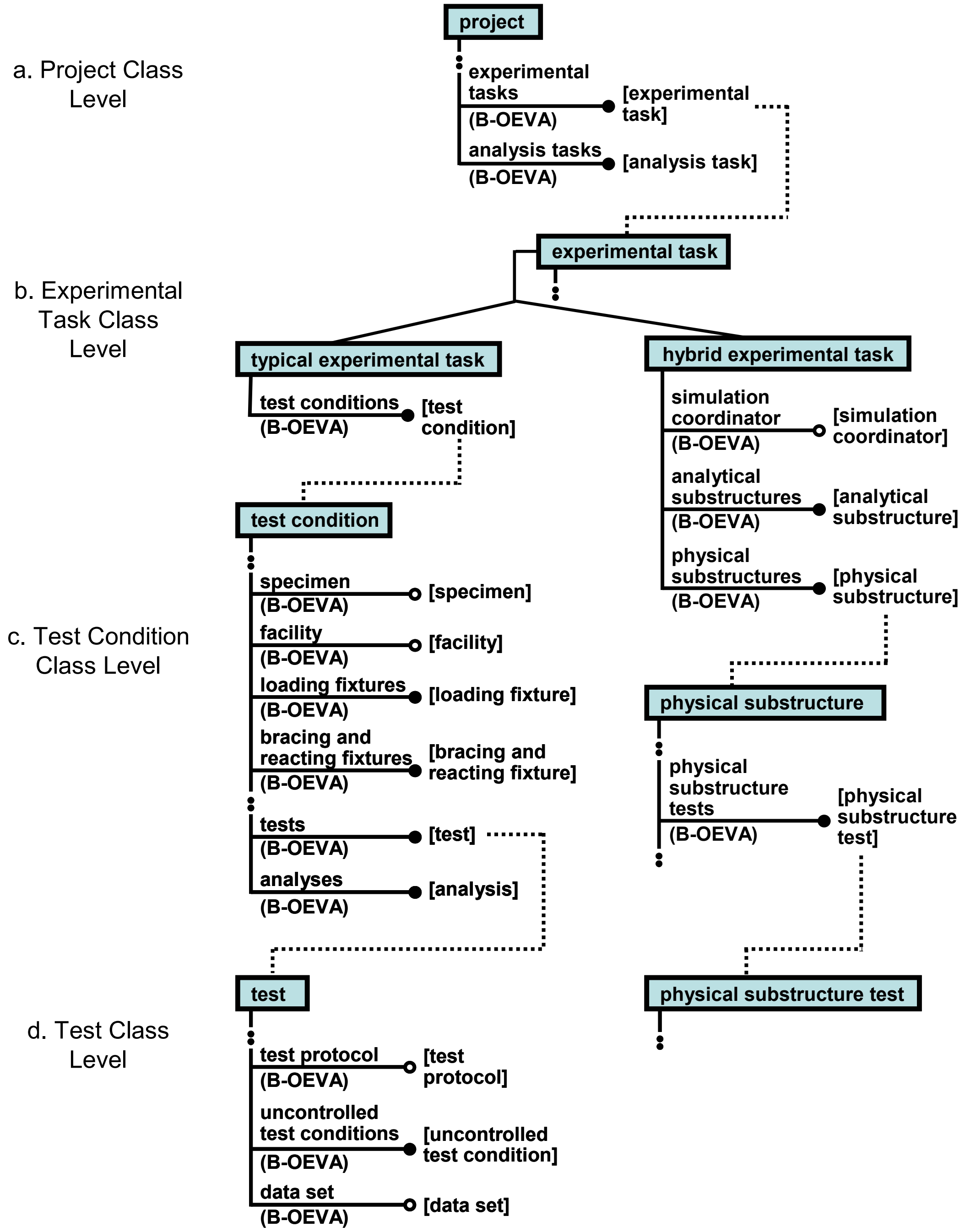


Figure 4.1 Levels of Classes in Class Hierarchy

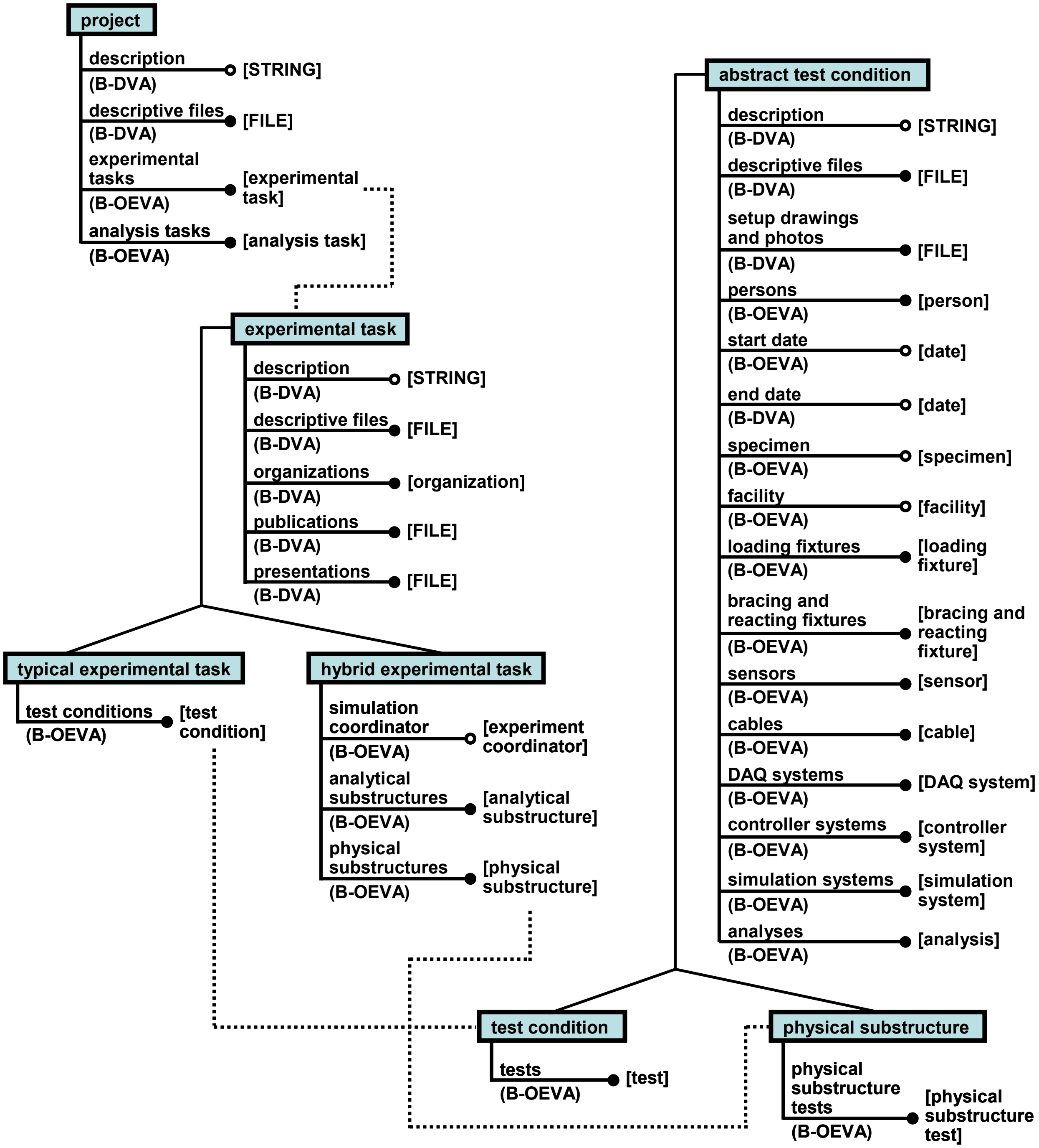


Figure 4.2 Project, Experimental Task, and Test Condition Classes

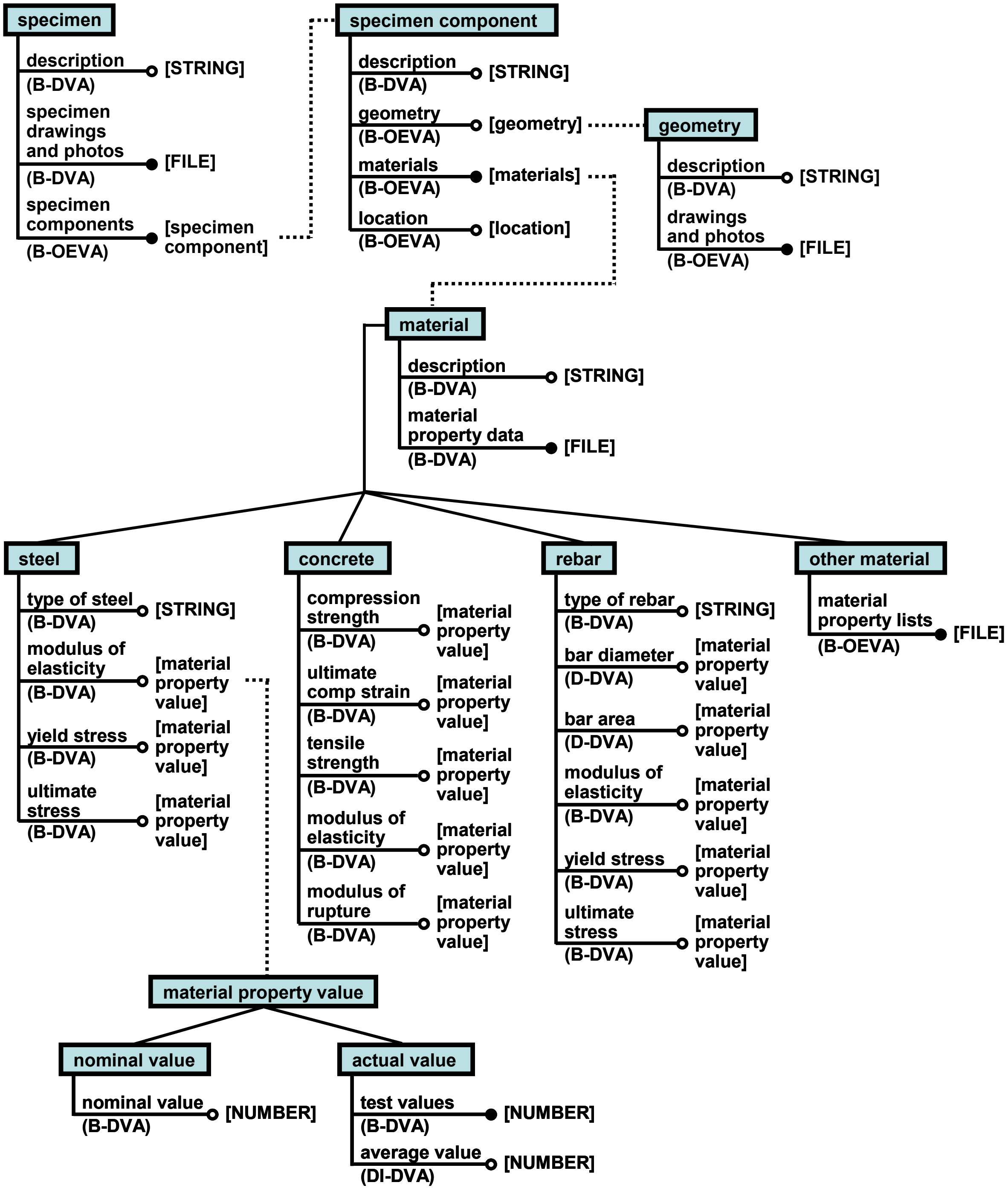


Figure 4.3 Specimen Classes

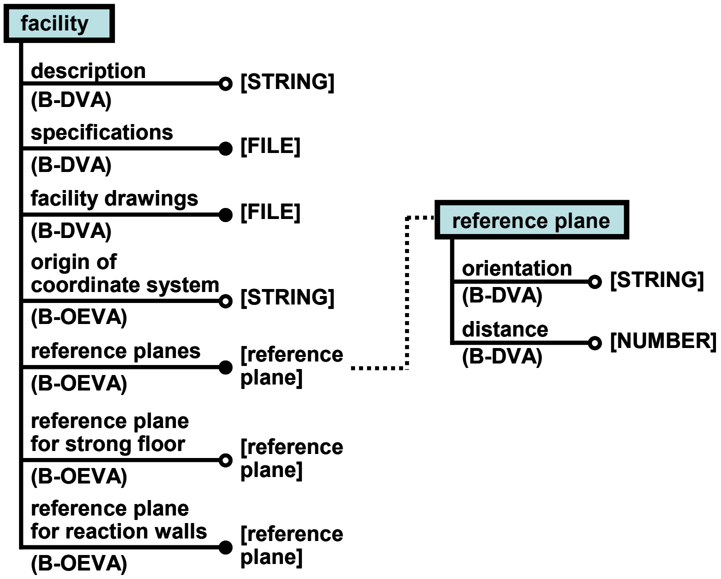


Figure 4.4 Facility Class

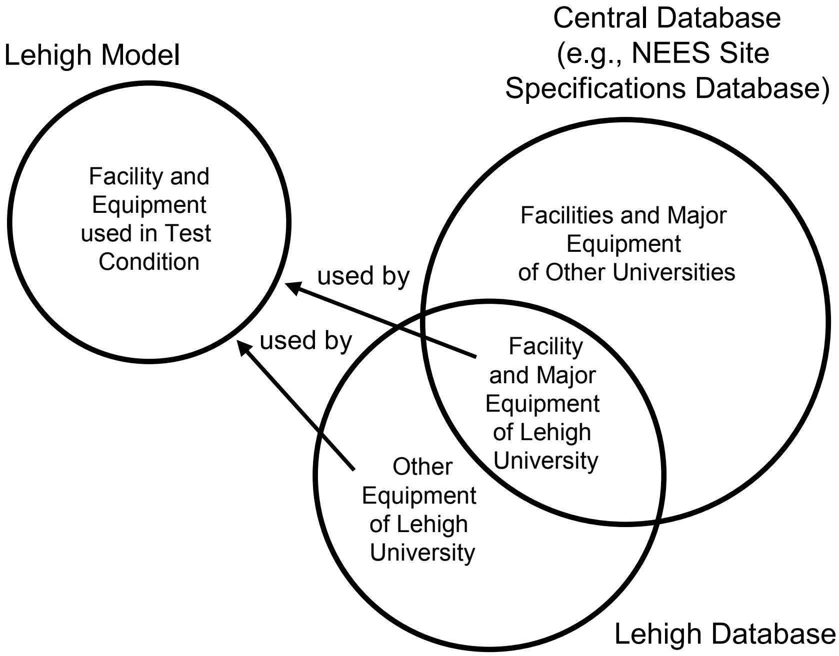
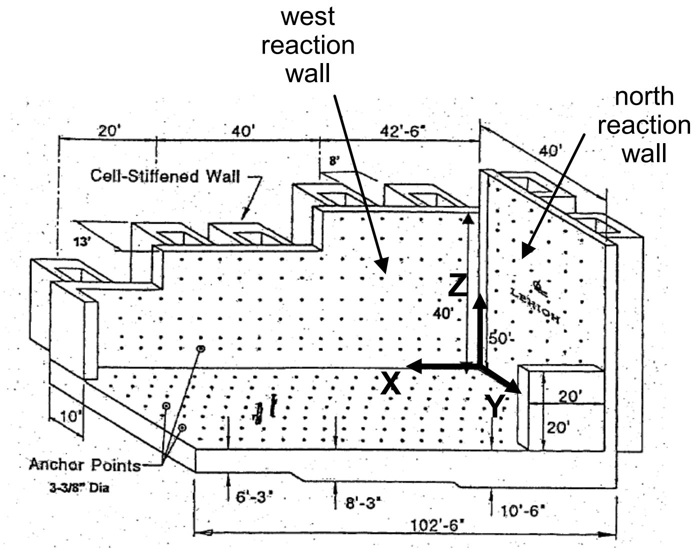
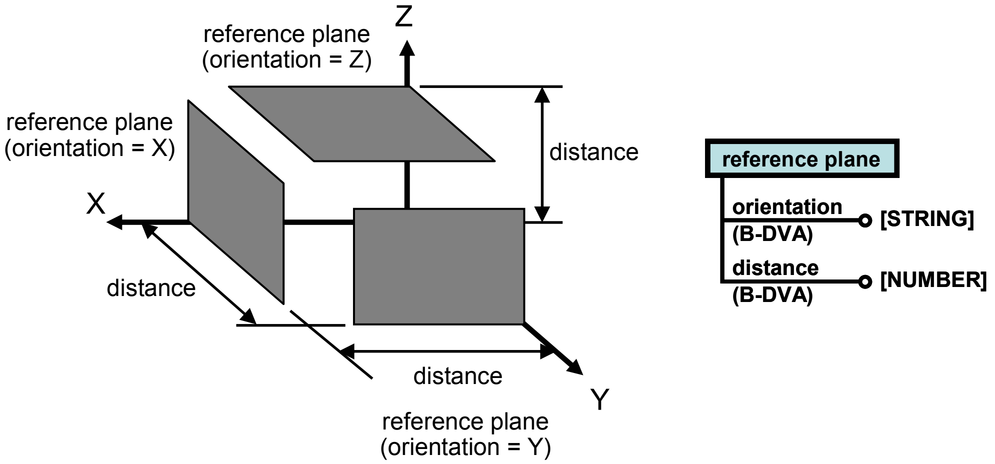


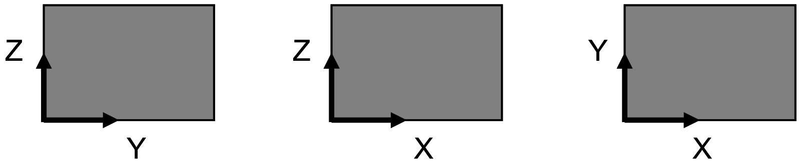
Figure 4.5 Data in Lehigh Model and Databases



a. Global Axes



b. Reference Planes



c. Reference Planes with Axes

Figure 4.6 Global Axes and Reference Planes at Lehigh Facility

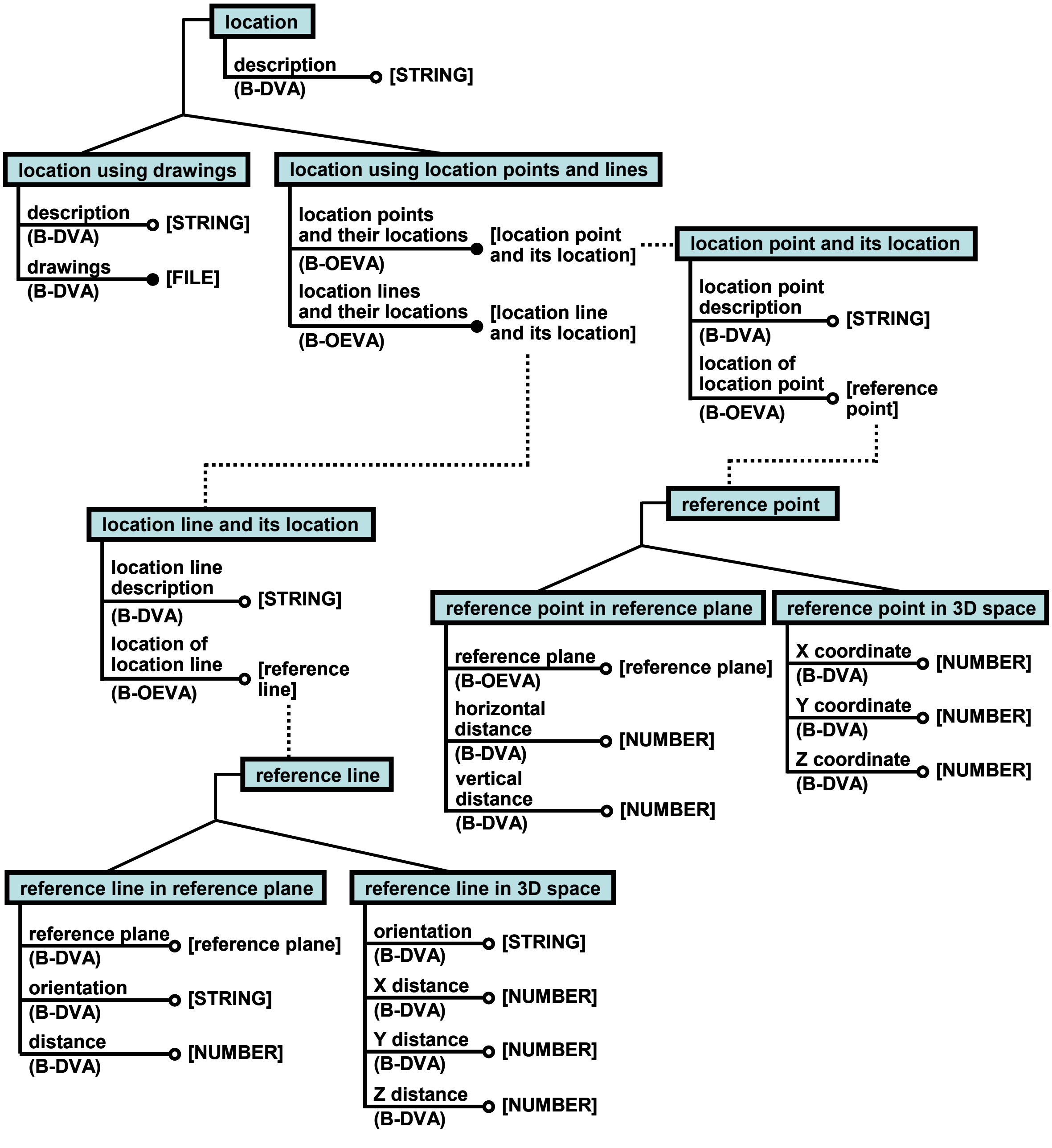
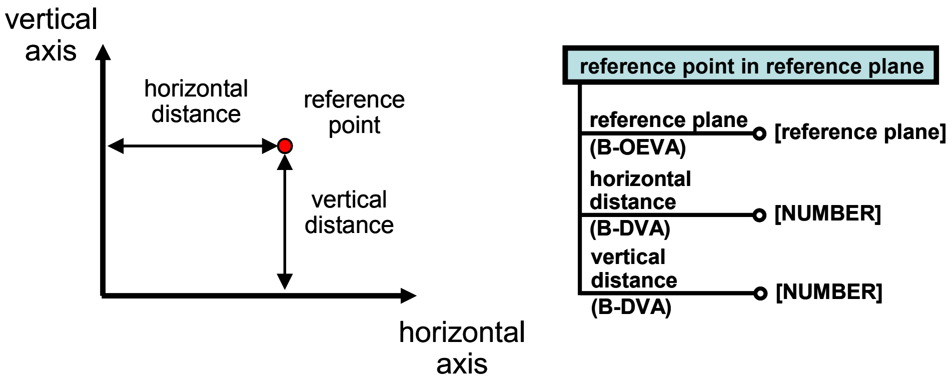
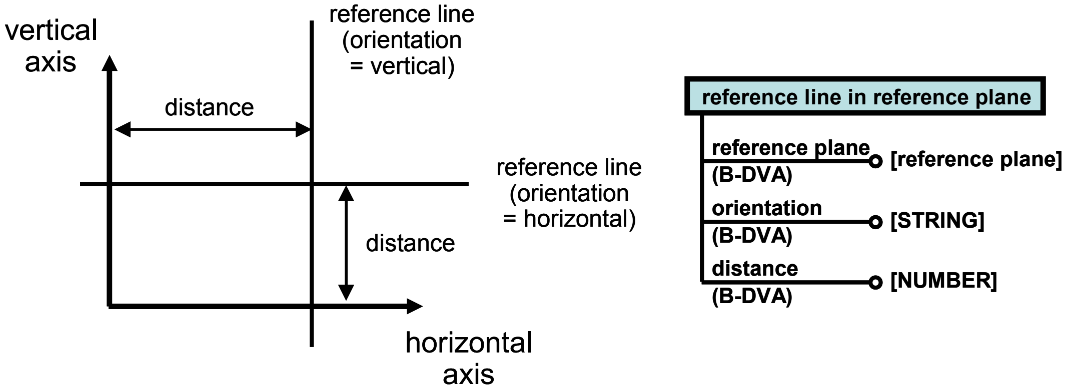


Figure 4.7 Location Class

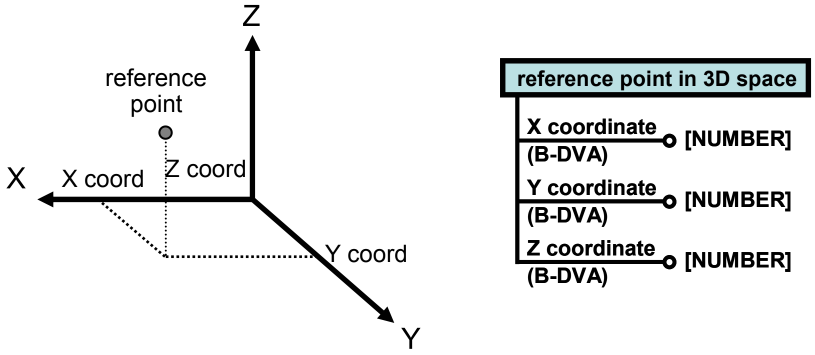


a. Reference Point in Reference Plane

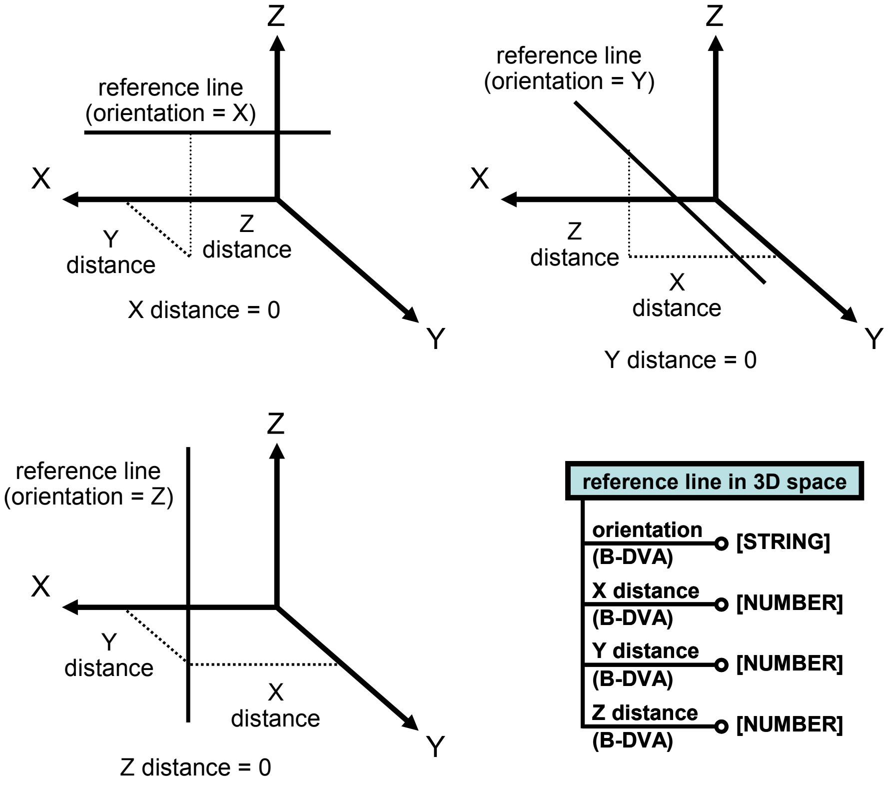


b. Reference Line in Reference Plane

Figure 4.8 Reference Point and Lines in Reference Planes

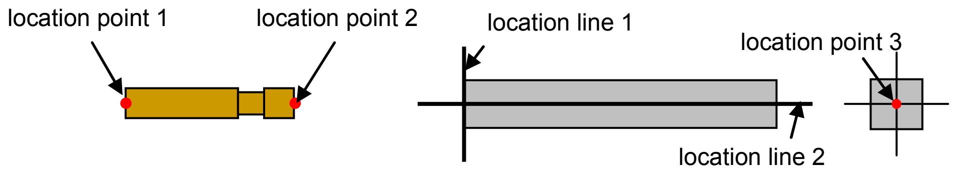


a. Reference Point in 3D Space

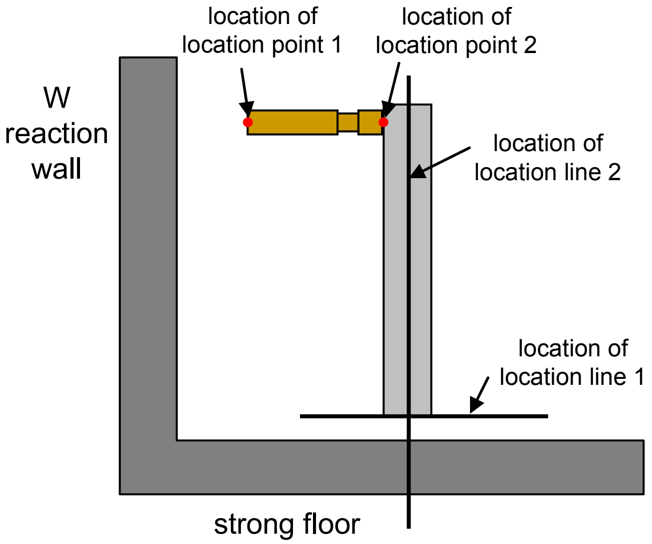


b. Reference Lines in 3D Space

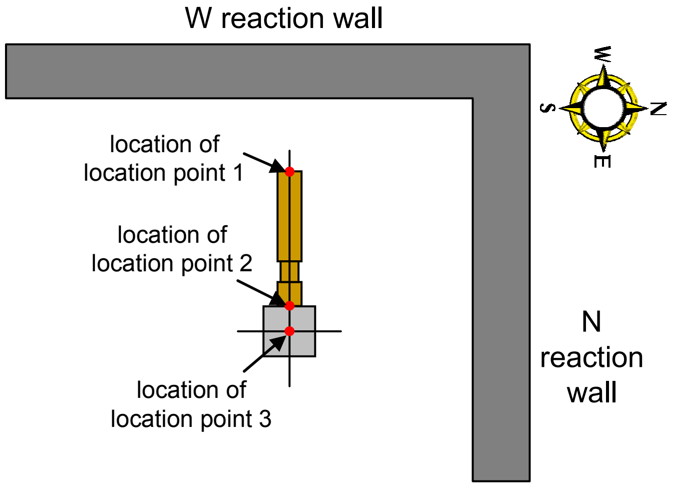
Figure 4.9 Reference Point and Lines in 3D Space



a. Location Points and Lines



b. Locations in Elevation



c. Locations in Floor Plan

Figure 4.10 Location Points and Lines and Their Locations

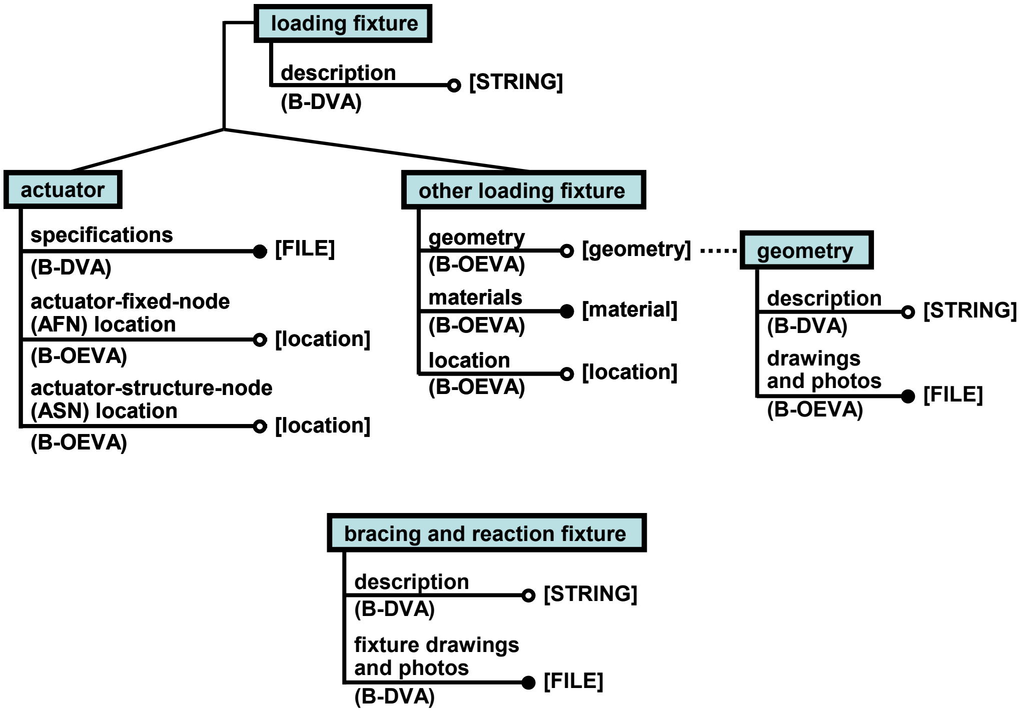


Figure 4.11 Loading Fixture and Bracing and Reaction Fixture Classes

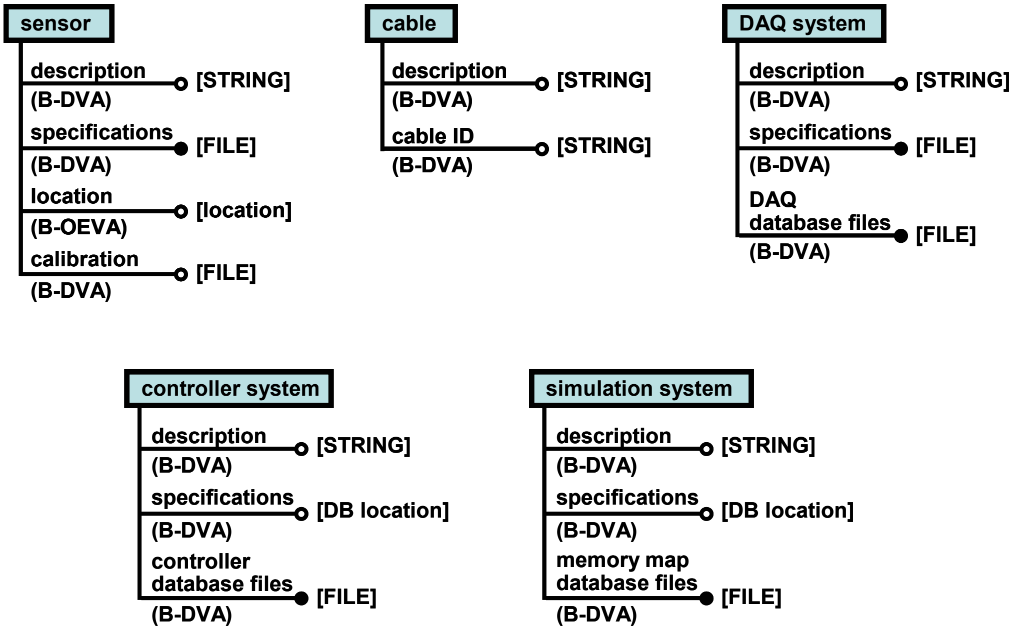


Figure 4.12 Classes for Data Acquisition and Test Control

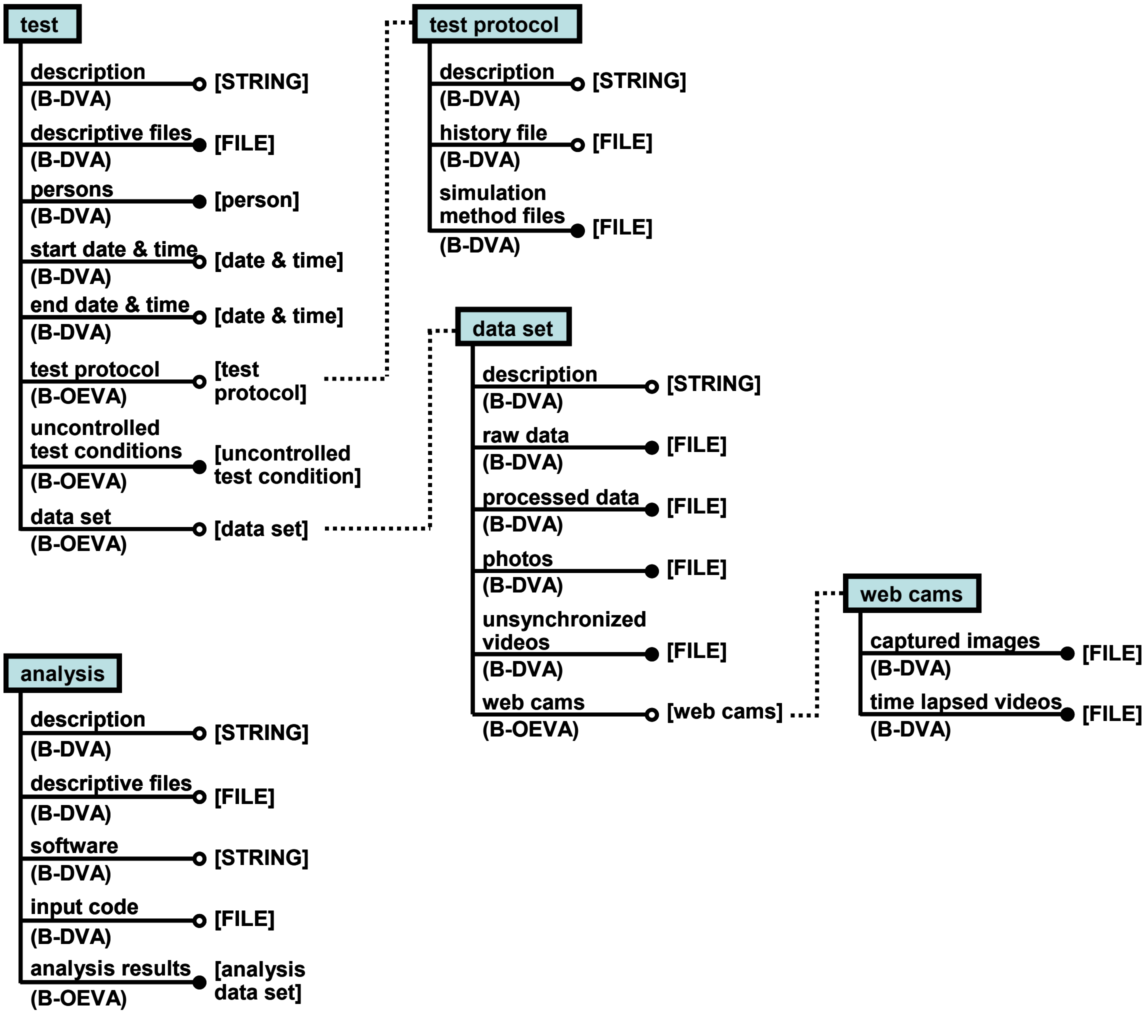


Figure 4.13 Test and Analysis Classes

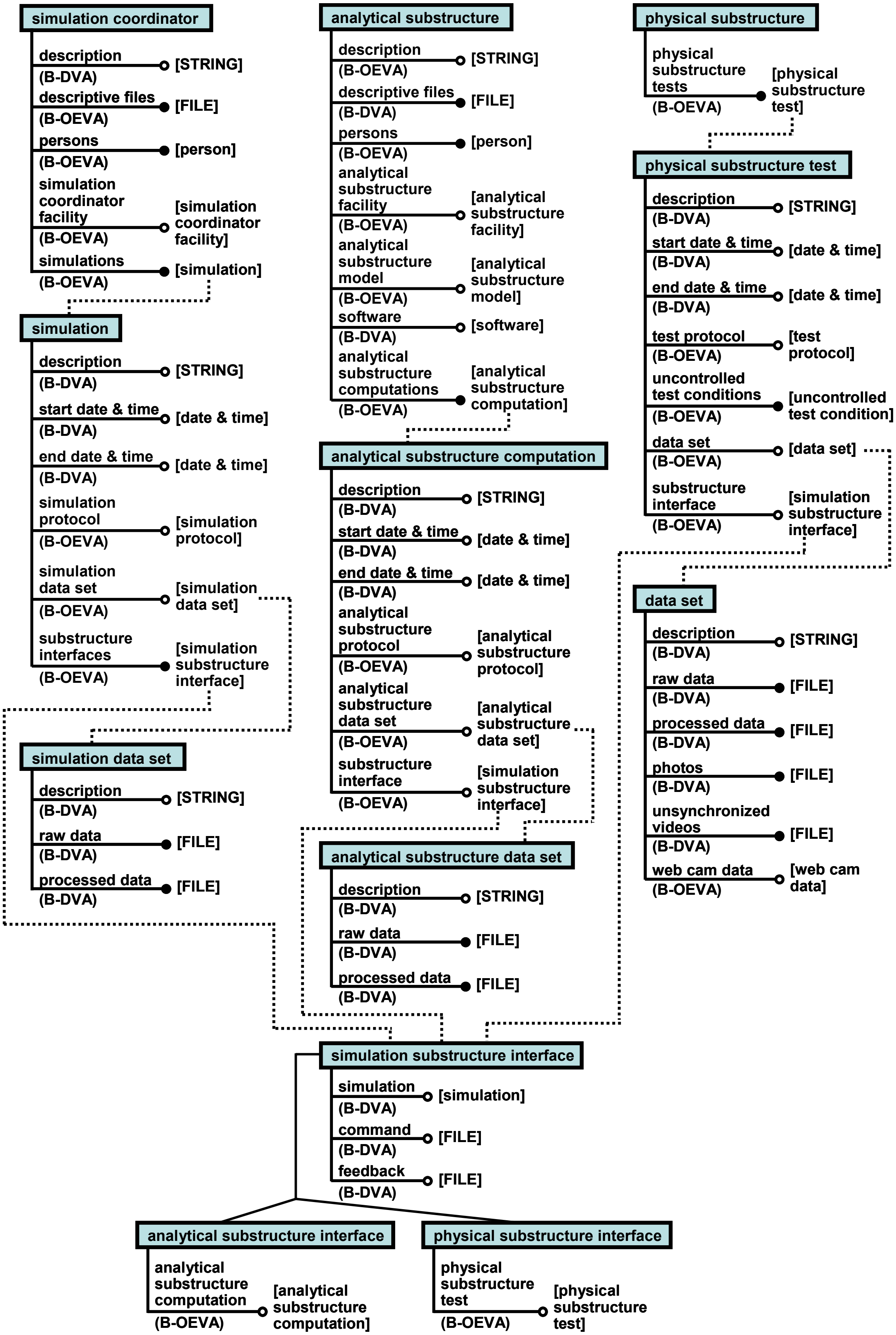
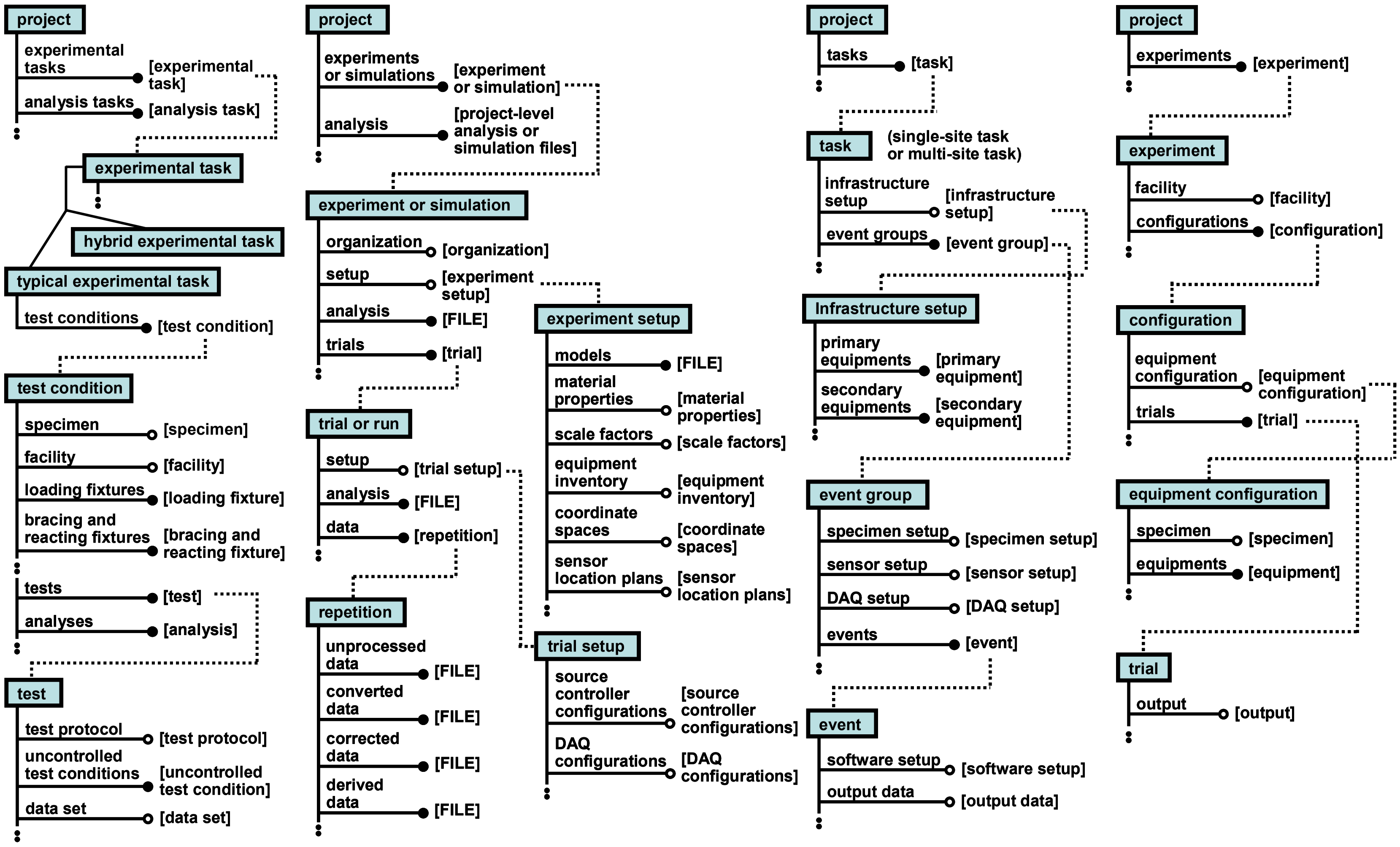


Figure 4.14 Hybrid Experimental Task Class



a. Lehigh Model

b. NEEScentral Model

c. Stanford Model

d. Oregon State Model

Figure 4.15 Comparison of Data Models for Structural Tests

CHAPTER 5

APPLICATION EXAMPLE OF LEHIGH MODEL

This chapter presents an application of the Lehigh Model developed in the previous chapters. The information for a structural test example is organized and represented, using the classes and attributes of the Lehigh Model. In the example, the model is represented as a system of folders and files. The implementation of the Lehigh Model as an internet application backed by a database is in progress and will be described in a future publication. Section 5.1 describes the structural test example. Section 5.2 compares the representation of the Lehigh Model with the system of folders and files. For the structural test example, section 5.3 discusses both the Lehigh Model and the system of the folders and files. Then section 5.4 discusses the observations from the example. Section 5.5 provides a summary.

5.1 Structural Test Example

The Lehigh Model presented in chapter 4 is applied to experiments on a steel moment connection which are part of a project for developing a self-centering moment resisting frame (SC-MRF) as an alternative to conventional steel moment resisting frame (MRF) systems (Ricles et al., 2001). Specifically, information about the tests of a post-tensioned (PT) friction connection for SC-MRFs with a bottom flange friction device (BFFD) (Wolski, 2006) is used for the application example of the Lehigh Model.

Figure 5.1 shows a prototype structure with the BFFD and the test setup (Wolski, 2006). The prototype beam section shown in Figure 5.1a is a W36x300. The scaled beam is a A572 Grade 50 W21x111 beam with a length of 12′–2½″, which represents part of the prototype beam scaled by 3/5. The scaled PT connection with a BFFD is tested in the setup shown in Figure 5.1b, where the beam is oriented in the vertical position for convenience in the lab. The specimen was designed to replicate the elongation of the strands in a SC-MRF, where the elongation of each PT strand is the same. To accomplish this, the strands are concentrated at the centroid of the beam specimen as shown in Figure 5.1b. A photo of the test setup is shown in Figure 5.1c.

The tests shown in Figure 5.1 were used to evaluate the performance of the PT connection with a BFFD (Wolski, 2006). The test matrix for the seven tests reported by Wolski (2006) is shown in Table 5.1. The tests and the associated data were obtained under different test conditions shown in Table 5.2. For example, Test 1 in Table 5.1 is Test C from Test Condition 2a in Table 5.2, and Test 2 in Table 5.1 Test C is from Test Condition 2b in Table 5.2. Some tests conducted under test conditions shown in Table 5.2 are not included in the tests shown in Table 5.1. The test conditions in Table 5.2 are considered for the structural test example of the Lehigh Model in this chapter.

5.2 Lehigh Model and System of Folders and Files

The information related to structural tests can be represented using the Lehigh Model and using a system of folders and files. The purpose of the system of folders and files is to serve as a temporary implementation of the model as it is being developed and tested.

Figure 5.2 shows the representational relationships between the Lehigh Model and the system of the folders and files.

Object 1 in Figure 5.2 is an instance of a class such as the project class in Figure 4.2. When the classes of the Lehigh Model are applied to a specific project, the objects are generated as instances of the classes of the model. Object 1 in Figure 5.2 includes attribute 1 (a data-valued and single-valued attribute), attribute 2 (a data-valued and multi-valued attribute), attribute 3 (an object entity-valued and single-valued attribute), and attribute 4 (an object entity-valued and multi-valued attribute). The values of these attributes come from the value sets of the attributes of the class of the Lehigh Model. For example, if attribute 1 in Figure 5.2a is the description attribute of the project class in Figure 4.2, the attribute 1 value in Figure 5.2a is a STRING (i.e., text) as shown in Figure 4.2.

For the information related to a structural test, represented as objects and values in Figure 5.2a, the corresponding folders and files can be organized as in Figure 5.2b. Object 1 in Figure 5.2a corresponds to the object 1 folder shown in Figure 5.2b. The attribute 1 value is in the attribute 1 value file. The two values of attribute 2 are in the two files of the attribute 2 folder. Similarly, the values of attribute 3 and attribute 4 in Figure 5.2a correspond to other folders in Figure 5.2b.

Figure 5.3 shows the differences between the Lehigh Model and the system of folders and files. Object A in Figure 5.3a includes attribute 1 whose value is a string. In the system of folders and files in Figure 5.3b, this string is in the text file of the object A folder. Note that in a proper implementation of the Lehigh Model, the string would be represented as a text string in a database, not in a text file. Object B in Figure 5.3a includes attribute 2 and object C includes attribute 3. The values of these two attributes are same, that is, object N. In the system of folders and files in Figure 5.3, the object N folder is located in the object B folder. The object C folder includes a text file which describes the path to the object N folder. Note that in a database implementation of the Lehigh Model, object N will be directly accessed from both object 2 and object 3.

5.3 Lehigh Model and System of Folders and Files for Application Example

The information related to the tests of the PT connection with the BFFD shown in Figure 5.1 and in Tables 5.1 and 5.2 has been represented using the Lehigh Model and the system of folders and files. The complete Lehigh Model for these tests includes a large number of objects, and the complete system includes a large number of folders and files. For simplicity, selected objects and corresponding folders and files are considered in the application example in this section. The Lehigh Model and the current system of folders and files at the four levels of classes (project class level, experimental task class level, test condition class level, and test class level) are presented.

5.3.1 Project Class Level

Figure 5.4 shows the Lehigh Model and the current system of folders and files at the project class level. The tests of the PT connection with the BFFD are an experimental task of the SC-MRF project, and the SC-MRF project object in Figure 5.4a is at the top level. The SC-MRF project object is from the project class in Figure 4.2. The SC-MRF project object in Figure 5.4a includes four attributes. The value of the description attribute is a string, and the value of the experimental task attribute is the BFFD experimental task object. There are no values for the attributes of the descriptive files and the analysis tasks at this time. Figure 5.4b shows the system of the folders and files which corresponds to the objects and values in Figure 5.4a. The string which is the value of the description attribute of the SC-MRF object in Figure 5.4a is in the text file in the SC-MRF project folder in Figure 5.4b.

5.3.2 Experimental Task Class Level

Figure 5.5 shows the Lehigh Model and the system of folders and files at the experimental task class level. The BFFD experimental task object in Figure 5.5a is the value of the experimental tasks attribute of the SC-MRF project in Figure 5.4a and is from the typical experimental task class in Figure 4.2. As described in chapter 4, the experimental task class in Figure 4.2 is a generalization of the typical experimental task class and the hybrid experimental task class, and the attributes of the experimental task class are inherited by the two lower level classes. The BFFD experimental task object in Figure 5.5a includes the attributes of both the experimental task class and the typical experimental task class in Figure 4.2. The values of the attributes of the BFFD experimental task in Figure 5.5 are a string, files, and other objects. Figure 5.5b shows the system of folders and files which corresponds to the objects and values in Figure 5.5a.

5.3.3 Test Condition Class Level

Figure 5.6 shows the Lehigh Model and the current system of folders and files at the test condition class level. The test condition 0 object in Figure 5.6a is one of the values of the test conditions attribute of the BFFD experimental task object in Figure 5.5a, and is from the test condition class in Figure 4.2. The abstract test condition class in Figure 4.2 is a generalization of the test condition class and the physical substructure condition class, and the attributes of the abstract test condition class are inherited by the two lower level classes. The test condition 0 object in Figure 5.6a includes the attributes of both the abstract test condition class and the test condition class in Figure 4.2. Figure 5.6b shows the system of folders and files which corresponds to the objects and values in Figure 5.6a.

The value of the setup drawings and photos attribute of the test condition 0 object in Figure 5.6a is a drawing file. This drawing file includes not only the setup drawing but also the drawings of specimen components such as the BFFD details drawing, shown on the second page of Figure 5.6b. It would be equally acceptable if the setup drawing file included only in the drawing of the test setup and the specimen components were shown in a separate drawing file.

The value of the specimen attribute of the test condition 0 object in Figure 5.6 is the specimen object. The details of the specimen object and corresponding folders and files are shown in Figure 5.7. The specimen object in Figure 5.7a is from the specimen class in Figure 4.3. The value of the specimen drawings and photos attribute of the specimen class in Figure 5.7a is a drawing file which is same as the drawing file of the test setup, shown previously in Figure 5.6 because the setup drawings file includes the drawings of the specimen. Again, it would be equally acceptable if the specimen drawings were in a separate file. In the system of the folders and the files in Figure 5.7b, the specimen drawings folder includes a text file which describes the path to the setup drawing file. The values of the specimen components attribute of the specimen object in Figure 5.7a are five other objects. Among the five objects, the BFFD object is shown in detail.

The BFFD object in Figure 5.7a is from the specimen component class in Figure 4.3. The values of the geometry, material, and location attributes of the BFFD object in Figure 5.7a are the objects BFFD geometry, BFFD steel, BFFD location using drawings. The drawings and photos attribute of the BFFD geometry object has two values. One is a drawing file which is the setup drawings file in Figure 5.6 because the setup drawings file includes the drawings of the BFFD. The other is a photo file for the BFFD components shown on the second page of Figure 5.7b. The BFFD steel object in Figure 5.7a is from the steel class in Figure 4.3 and includes the material property data attribute whose value is a material property table shown in the second page of Figure 5.7b. The slotted plate in the table is used for the BFFD. The BFFD location using drawings object in Figure 5.7a is from the location using drawings class in Figure 4.7a. The location of the BFFD is described using the setup drawings file and the value of the drawings attribute in Figure 5.7a is the setup drawings file.

The value of the facility attribute of the test condition 0 object in Figure 5.6 is the RTMD facility object. The details of the RTMD facility object and corresponding folders and files are shown in Figure 5.8. The RTMD facility object is from the facility class in Figure 4.4. The value of the specifications attribute of the RTMD facility in Figure 5.8a is a web file from the NEES Site Specification Database and the homepage of the RTMD facility is shown in Figure 5.8b.

5.3.4 Test Class Level

Figure 5.9 shows the Lehigh Model and the system of folders and files at the test class level. The test A object in Figure 5.9a is one of the values of the tests attribute of the test condition 0 object in Figure 5.6a, and is from the test class in Figure 4.13. The values of the persons attribute of the test A object in Figure 5.9a are a subset of the values of the persons attribute of the test condition 0 object in Figure 5.6a. The value of the data set attribute of the test A object in Figure 5.9a is the test A data set object. The attributes of the test A data set include the raw data, photos, and web cams. The corresponding Excel files, JPG files, and video files are shown in Figure 5.9b.

5.4 Discussion

The Lehigh Model and the corresponding system of folders and files for the structural test example were presented in the previous section. A limited number of objects and folders and files were considered, but the example has shown how the information related to structural experiments can be organized using the Lehigh Model. The system of folders and files has been used to illustrate the application example in more detail and has served as an interim implementation for developing the model. Figure 5.10 shows the folders and files created for the application example in Windows Explorer.

As described in Section 5.2, there are differences between the Lehigh Model and the system of folders and files. A string which is the value of an attribute in the Lehigh

Model is in a text file in the current system. An object may be the value of two or more different attributes in the Lehigh Model, but in the system of the folders and files the object is only in one folder and text files describing the path to the object are in the other folders. This representation in the system of folders and files will be unnecessary when the model is implemented in a database. A string will be stored as a string in the implemented system, and the same object will be accessed from the different locations in the implemented system.

The structural test example used for the application example was based on a set of tests carried out at the RTMD facility at Lehigh University. Most of the information related to the tests was generated before the Lehigh Model was developed, making it inconvenient to fit into the organization of the Lehigh Model. For example, all the AutoCAD drawings are in a single drawing file that includes the setup drawings, specimen drawings and other component drawings. Considering the structure of the Lehigh Model, this file could be divided into several files. The appropriate number of drawing files may depend on the size and complexity of the structural experiments. For small scale tests, only one file may be enough for all the drawings. Large-scale tests may require many drawings and the use of several files may be more appropriate.

The application example did not show all features of the Lehigh Model. The example experiments were carried out at one facility, and test conditions using different facilities were not presented. The locations of the specimen components were described using the drawing files, and an example for the location using the location point and lines was not provided. The application example is a typical experimental task, not a hybrid experimental task, and the parts of the model related to hybrid experimental tasks were not discussed. Even though the application example is limited, the example shows how the Lehigh Model organizes information related to structural experiments.

5.5 Summary

This chapter has presented an application of the Lehigh Model to structural tests of a PT friction connection with a BFFD, performed at the RTMD facility at Lehigh University. The information related to the tests is represented both as the objects and attribute values in the Lehigh Model and as a system of folders and files. The objects and attribute values are from the classes and attributes developed for the Lehigh Model in chapter 4. The objects and attribute values for the application example are shown at the four levels of classes (project class level, experimental task class level, test condition class level, and test class level).

Table 5.1 Matrix of Tests Reported (Wolski, 2006)

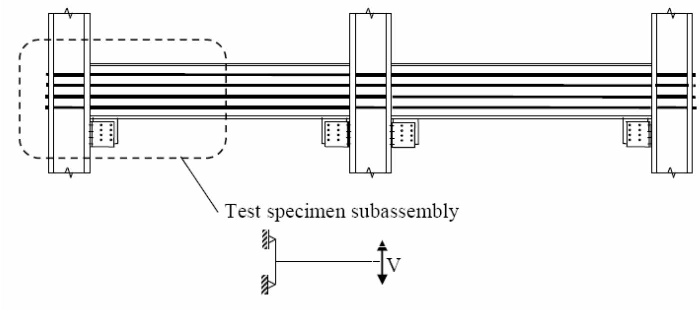
Test No.	Loading Protocol	Freq. (Hz)	$\theta_{r,max}$ (rads)	$T_{o,n}$ (kips)	$N_{o,n}^{(1)}$ (kips)	$F_{f,n}^{(2)}$ (kips)	Keeper Angle	Slotted Plate Weld	Comments
1	CS	0.05	0.035	500.0	68	54.4	SL1	F	
2	CS	0.05	0.030	500.0	132	105.6	SL2	F	
3	CS	0.05	0.030	500.0	132	105.6	SL2	FR	MSR
4	EQ	⅛ x real time	0.0245	500.0	132	105.6	SL2	FR	MSR
5	CS	0.05	0.065	500.0	132	105.6	SL2	FR	MSR
6	CS	0.05	0.035	500.0	132	105.6	SL2	CJP	MSR
7	CS	0.05	0.065	500.0	152	121.6	SL2	CJP	MSR

Legend

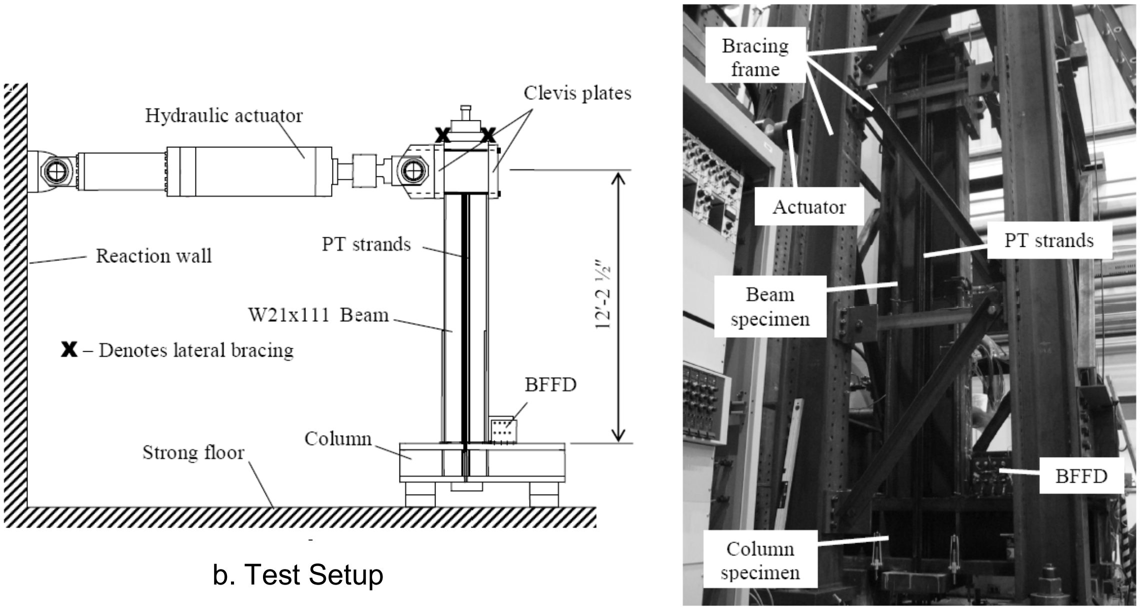
CJP: Complete joint penetration weld
CS: Cyclic symmetric
EQ: Chi-Chi MCE level earthquake response
F: Fillet
FR: Fillet repair
MSR: Mill scale removed from slotted plate
SL1: Slotted keeper angle
SL2: Slotted keeper angle with double nut on sliding bolt
(1): $N_{o,n} = n_b T_m$
(2): $F_{f,n} = 2\mu N_{o,n}$

Table 5.2 Test Conditions and Tests

Test Conditions	Description of Test Conditions	Tests
Test Condition 0	Test Condition 0 was used to evaluate the operation of the instrumentation, seat the beam, and work out any issues with the test setup. In this test condition, the web keeper angle was used, and the top flange slotted keeper angle was not used.	Test A, Test B
Test Condition 1	The web keeper angles were used, and the top flange slotted keeper angle was not used. Test Condition 1 was used to evaluate the performance of the BFFD with a reduced friction force.	Test A
Test Condition 2a	The web keeper angles were removed and the top flange slotted keeper angle was installed. Test Condition 2a was used to evaluate the performance of the BFFD with a reduced friction force; however, in Test Condition 2b, no data was recorded with the DAQ system. Therefore, the tests were repeated under Test Condition 2b.	Test A, Test B, Test C (Thesis Test 1), Test Cx, Test Cx2, Test D, Test Dx
Test Condition 2b	In Test Condition 2b, the slotted plate fillet weld was repaired, and a continuous weld toe was installed at the top edge of the slotted plate. Test Condition 2b was used to evaluate the performance of the BFFD with the design friction force.	Test A, Test B, Test C (Thesis Test 2), Test D, Test F, Test Fx, Test Fy
Test Condition 3	No test were conducted in Test Condition 3. Initially, Test Condition 3 was to be used to evaluate effectiveness of the web keeper angle, but prior test conditions served this purpose.	
Test Condition 4	No test were conducted in Test Condition 4. Initially, Test Condition 4 was to be used to evaluate the lateral and transverse movement of the beam at the beam-column interface without the web keeper angle, but prior test conditions served this purpose.	
Test Condition 5	Test Condition 5 was used to evaluate the performance of the BFFD with the design friction force under EQ loading and also the evaluate the effect of bolt bearing.	Test A (Thesis Test 3), Test B (Thesis Test 4), Test C (Thesis Test 5)
Test Condition 6	In Test Condition 6, all of the friction bolts were replaced with new ungauged bolts. Also, the slotted plate was re-attached to the beam using a complete joint penetration (CJP) weld. Test Condition 6 was used to evaluate the flexibility of the column angles under varying levels of friction force, and also to evaluate the effect of bolt bearing. The slotted plate of the BFFD was welded to the beam using a complete joint penetration (CJP) weld.	Test A (Thesis Test 6), Test B (Thesis Test 7)
Test Condition X	Test Condition X was used to evaluate the movement of the slotted plate with respect to the friction bolts. This was accomplished by removing the steel column angles and replacing them with the plywood/plexiglass column angles. The web keeper angle was used, and the top flange slotted keeper angle was not used.	Test A, Test B



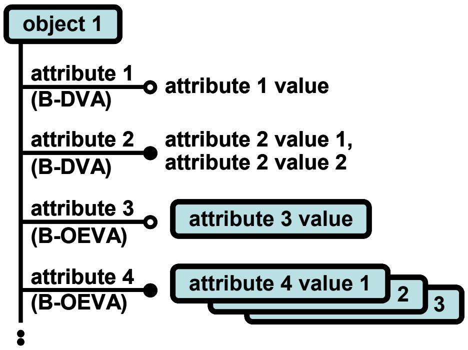
a. Prototype Structure



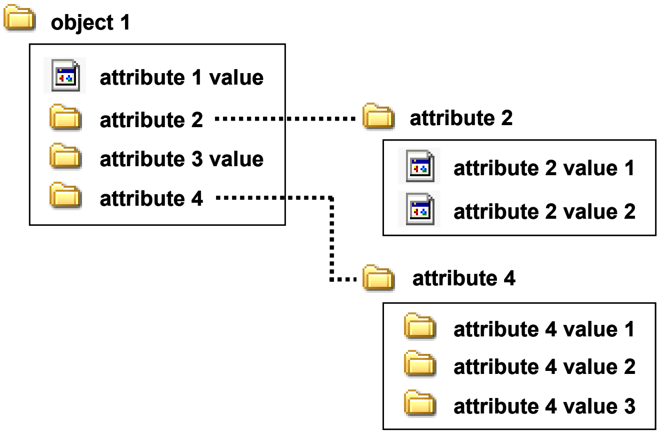
b. Test Setup

c. Photo of Test Setup

Figure 5.1 Test of PT Connection with BFFD (after Wolski, 2006)

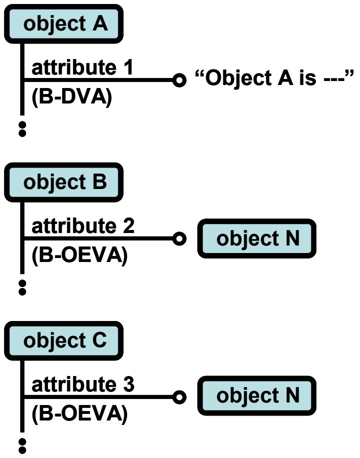


a. Lehigh Model

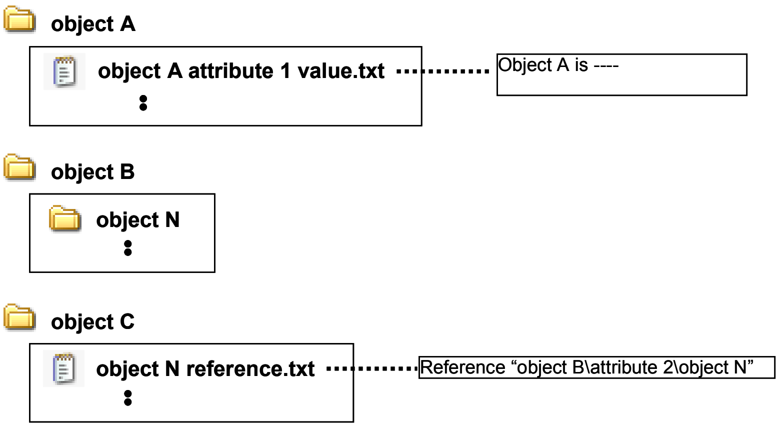


b. System of Folders and Files

Figure 5.2 Lehigh Model and System of Folders and Files

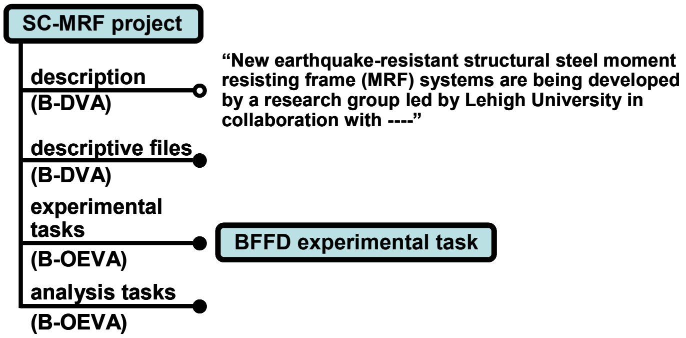


a. Lehigh Model



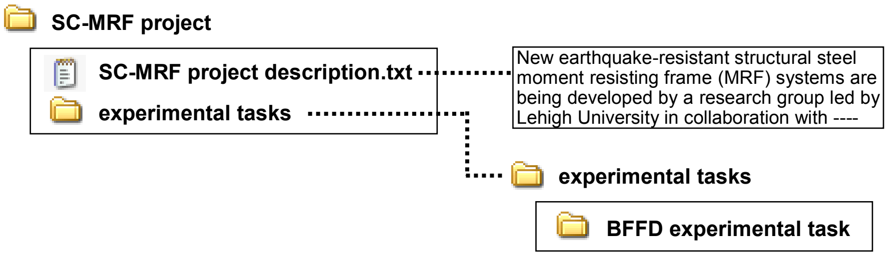
b. Current System of Folders and Files

Figure 5.3 Differences between Lehigh Model and System of Folders and Files



"New earthquake-resistant structural steel moment resisting frame (MRF) systems are being developed by a research group led by Lehigh University in collaboration with ----"

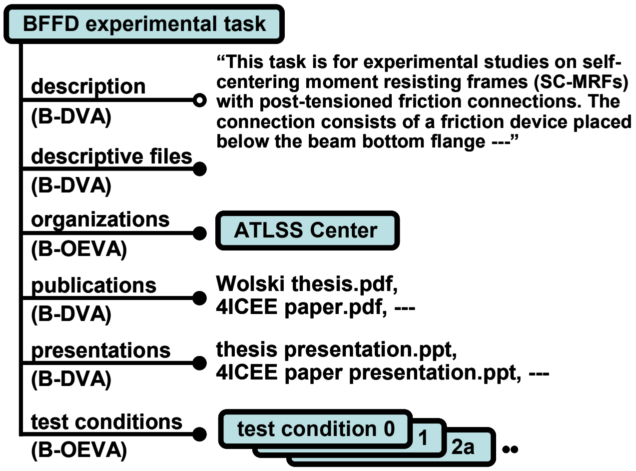
a. Lehigh Model



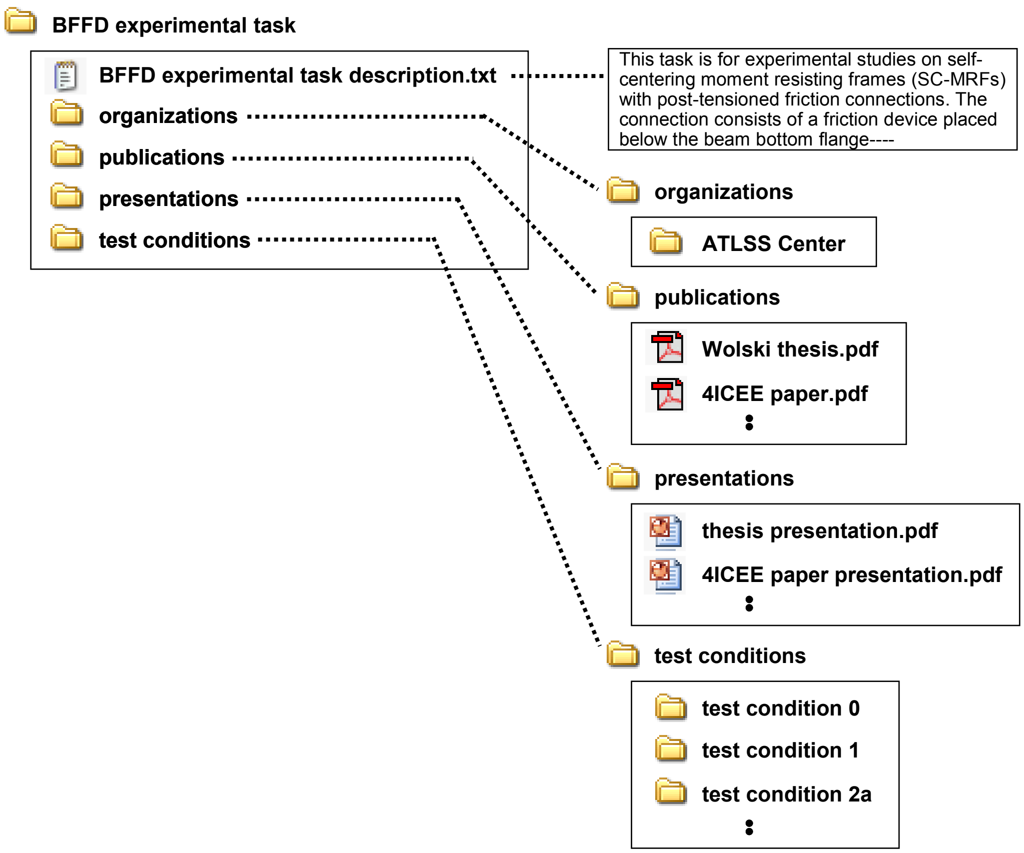
New earthquake-resistant structural steel moment resisting frame (MRF) systems are being developed by a research group led by Lehigh University in collaboration with ----

b. Current System of Folders and Files

Figure 5.4 Application Example at Project Class Level

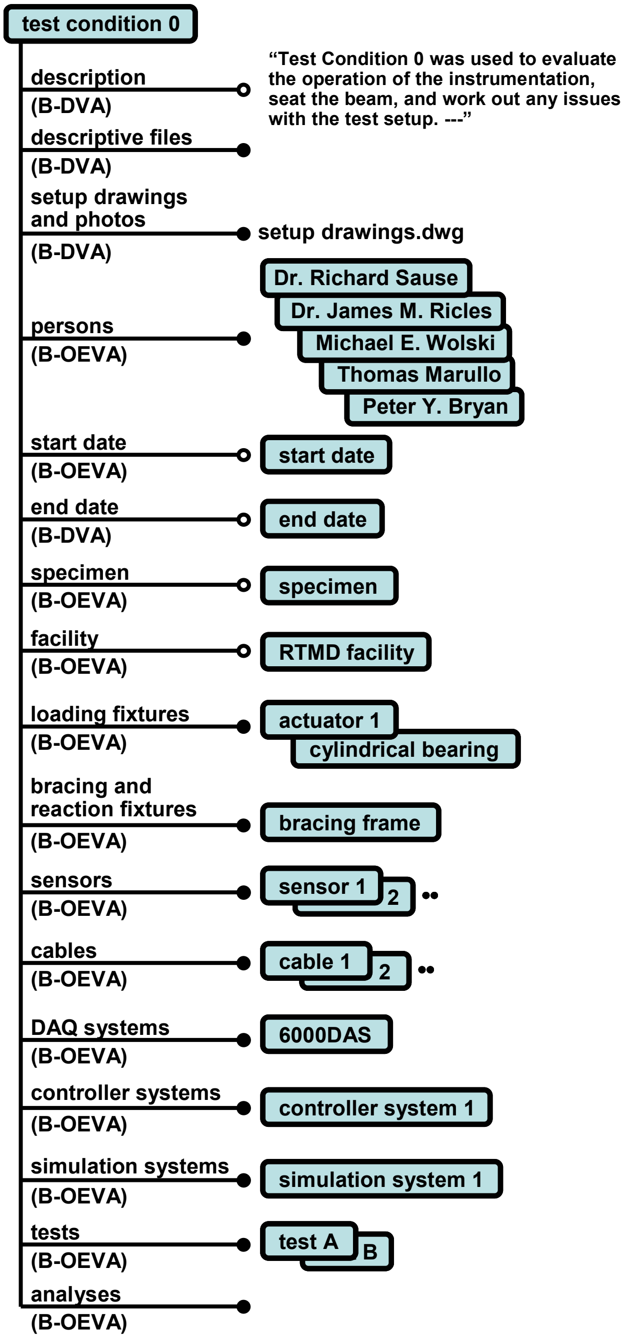


a. Lehigh Model



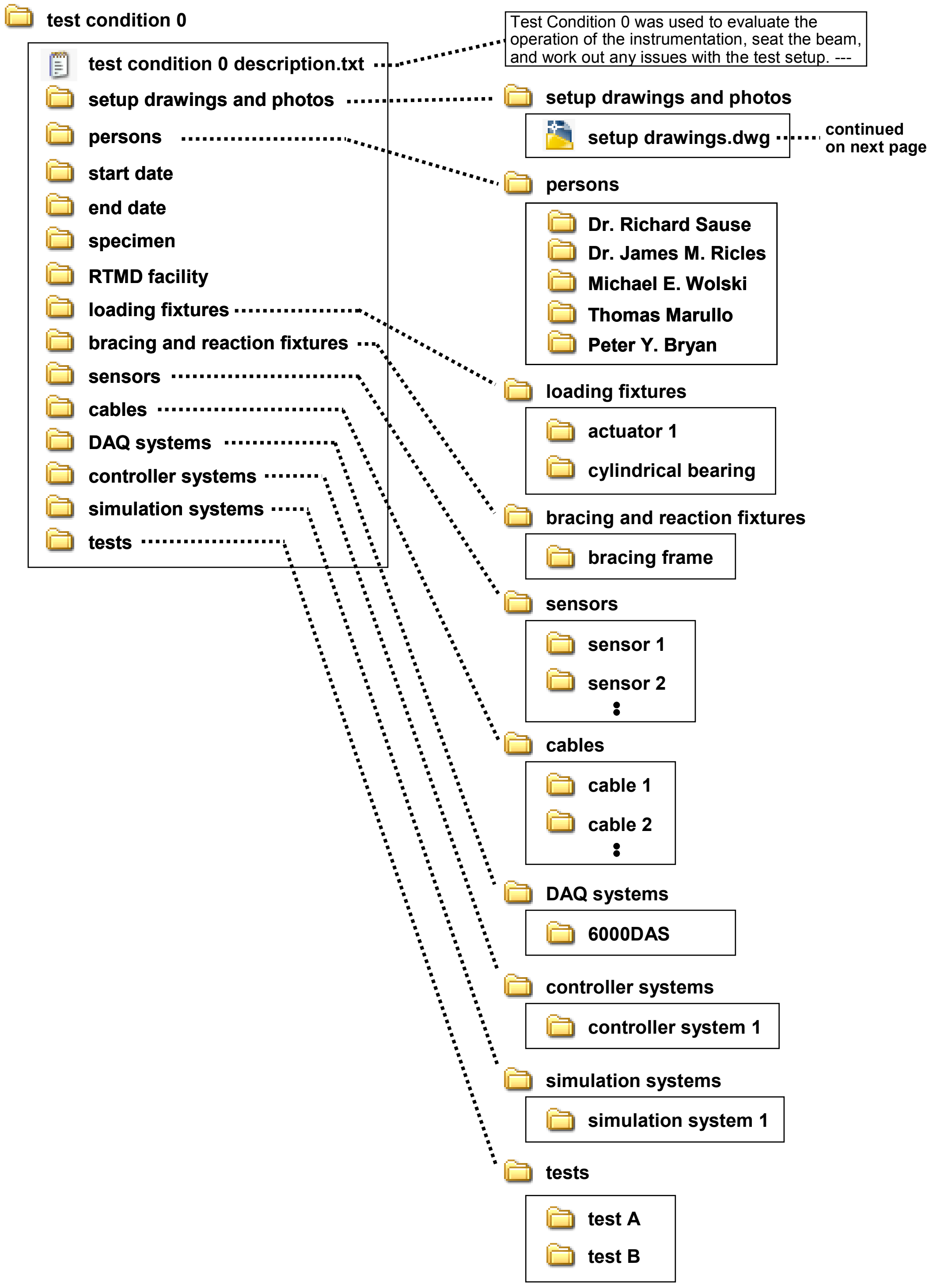
b. Current System of Folders and Files

Figure 5.5 Application Example at Experimental Task Class Level



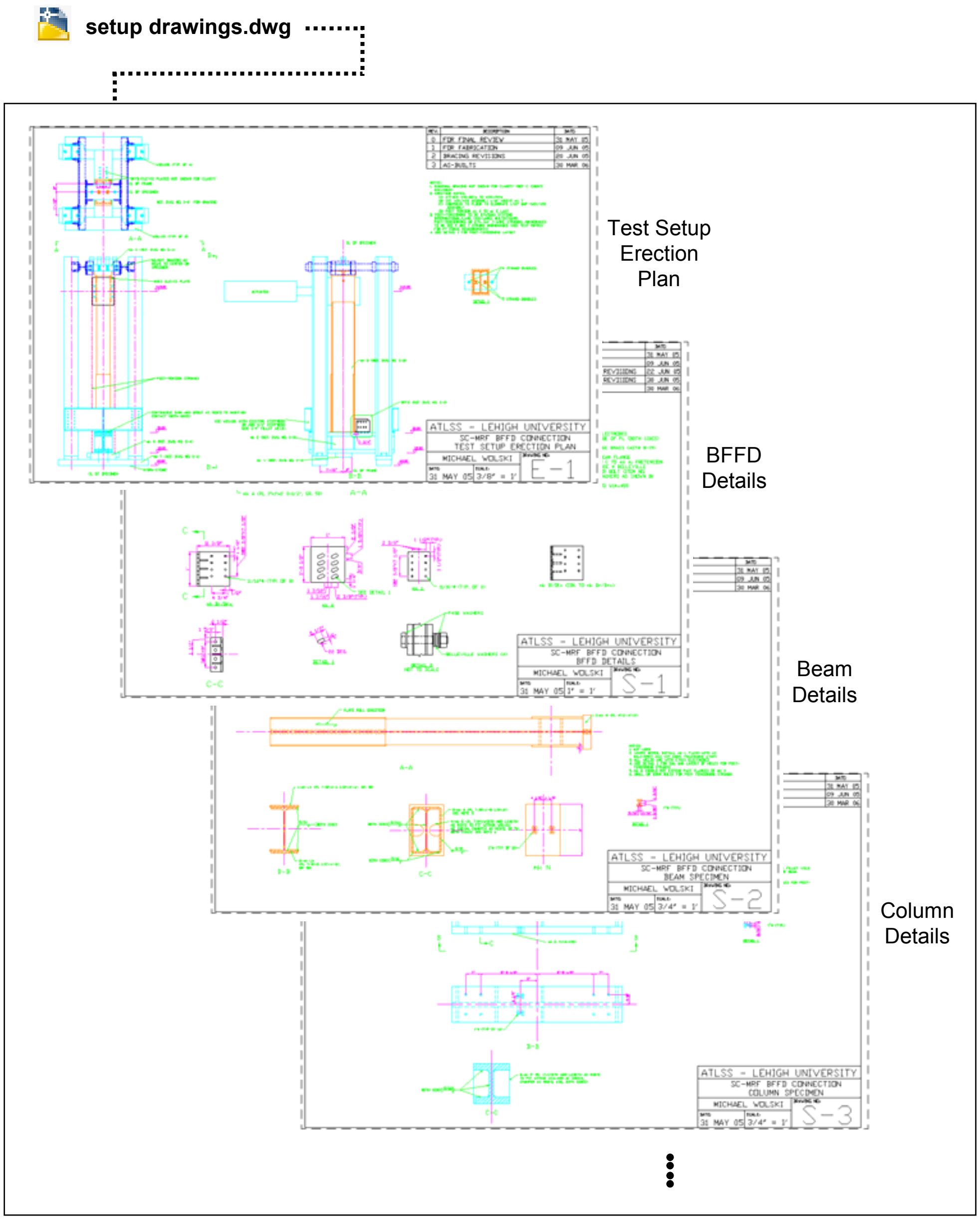
a. Lehigh Model

Figure 5.6 Application Example at Test Condition Class Level



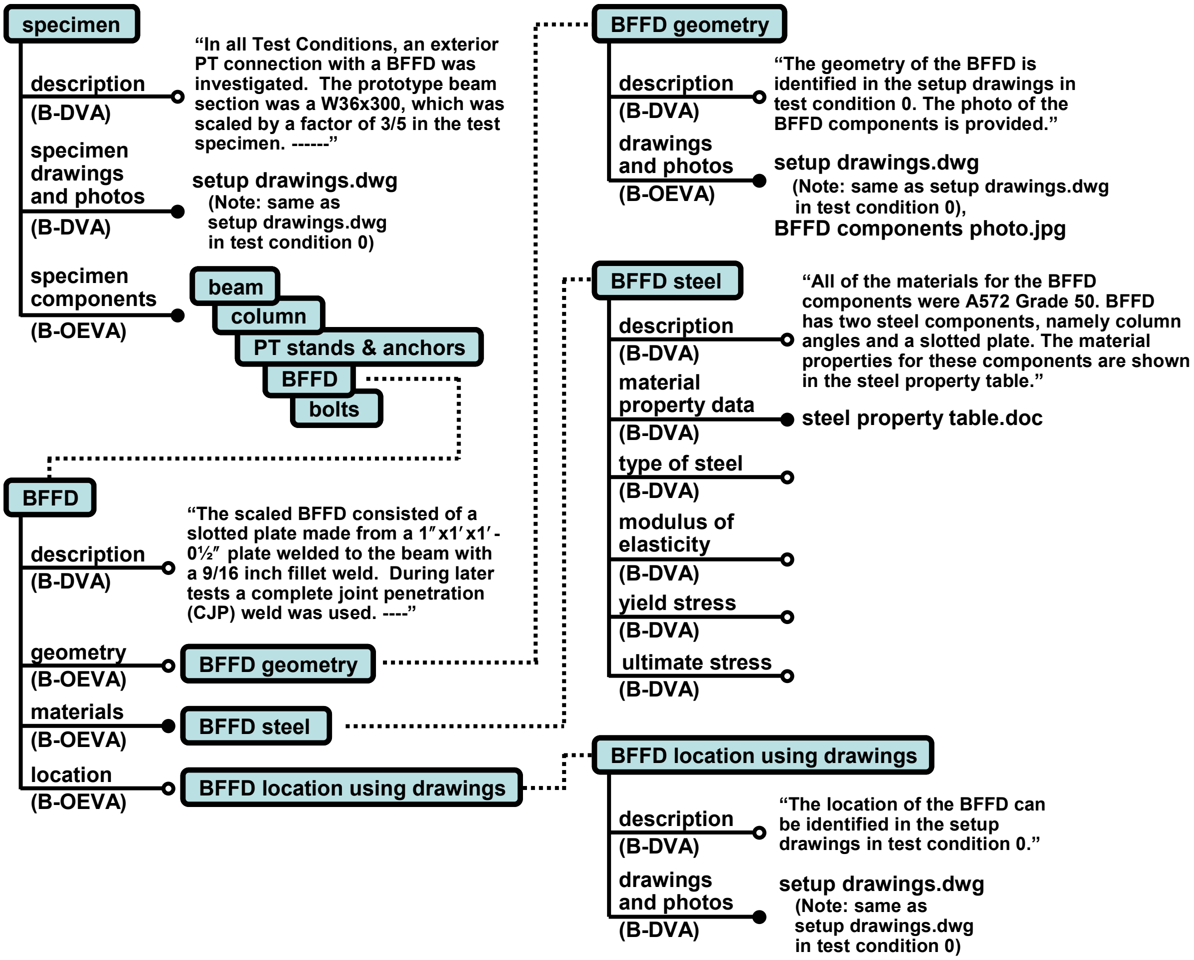
b. System of Folders and Files

Figure 5.6 Application Example at Test Condition Class Level (continued)



b. System of Folders and Files (continued)

Figure 5.6 Application Example at Test Condition Class Level (continued)



"In all Test Conditions, an exterior PT connection with a BFFD was investigated. The prototype beam section was a W36x300, which was scaled by a factor of 3/5 in the test specimen. ------"

"The scaled BFFD consisted of a slotted plate made from a 1″x1′x1′-0½″ plate welded to the beam with a 9/16 inch fillet weld. During later tests a complete joint penetration (CJP) weld was used. ----"

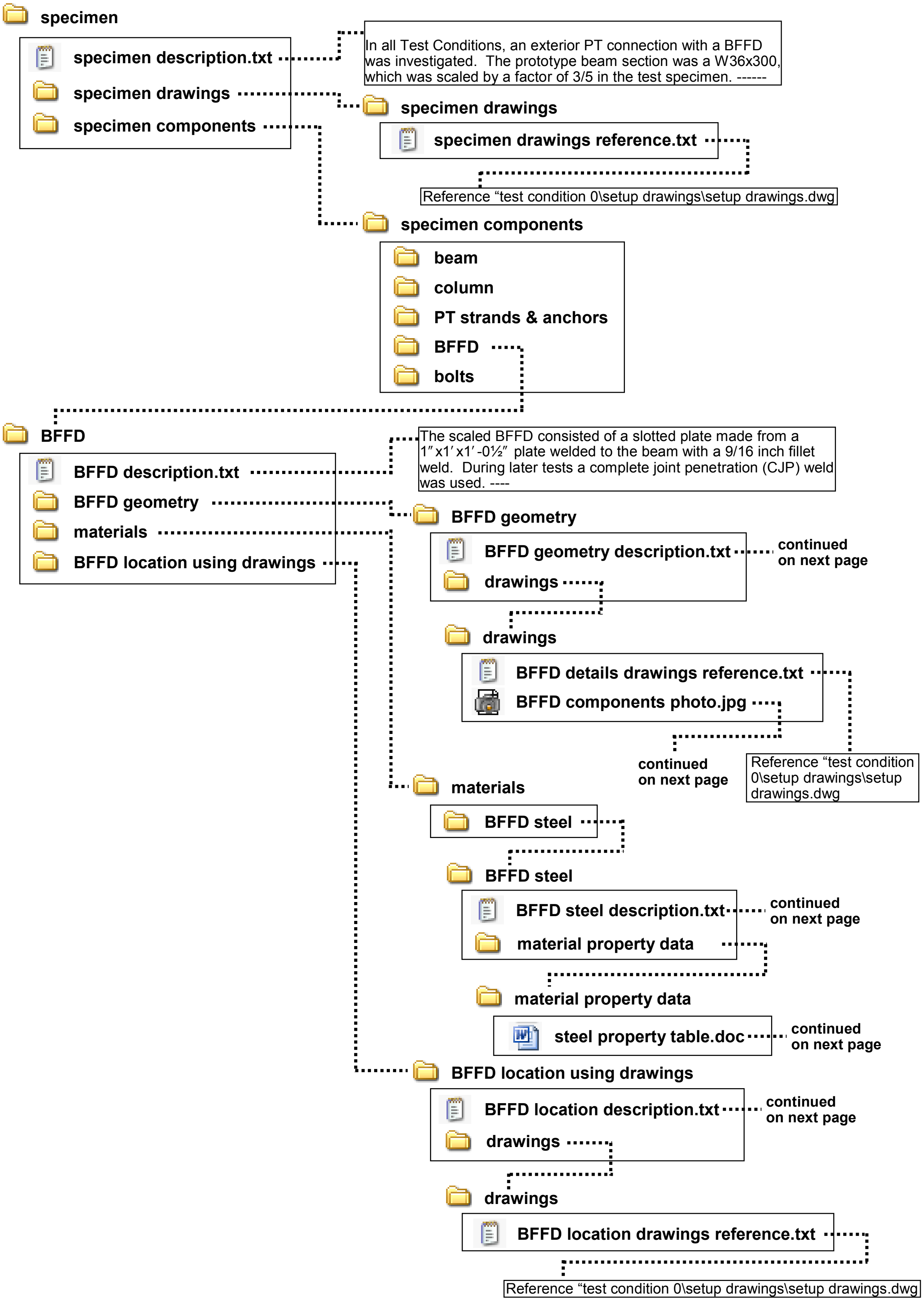
"The geometry of the BFFD is identified in the setup drawings in test condition 0. The photo of the BFFD components is provided."

"All of the materials for the BFFD components were A572 Grade 50. BFFD has two steel components, namely column angles and a slotted plate. The material properties for these components are shown in the steel property table."

"The location of the BFFD can be identified in the setup drawings in test condition 0."

a. Lehigh Model

Figure 5.7 Application Example for Specimen Object



In all Test Conditions, an exterior PT connection with a BFFD was investigated. The prototype beam section was a W36x300, which was scaled by a factor of 3/5 in the test specimen. ------

Reference “test condition 0\setup drawings\setup drawings.dwg

The scaled BFFD consisted of a slotted plate made from a 1″x1′x1′-0½″ plate welded to the beam with a 9/16 inch fillet weld. During later tests a complete joint penetration (CJP) weld was used. ----

Reference “test condition 0\setup drawings\setup drawings.dwg

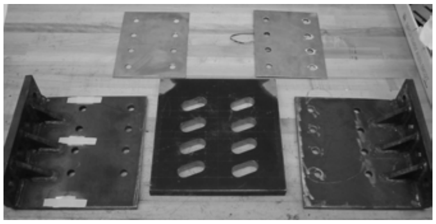
Reference “test condition 0\setup drawings\setup drawings.dwg

b. System of Folders and Files

Figure 5.7 Application Example for Specimen Object (continued)

BFFD geometry description.txt ······ The geometry of the BFFD is identified in the setup drawings in test condition 0. The photo of the BFFD components is provided.

BFFD components photo.jpg ········



BFFD steel description.txt ············ All of the materials for the BFFD components were A572 Grade 50. BFFD has two steel components, namely column angles and a slotted plate. The material properties for these components are shown in the steel property table.

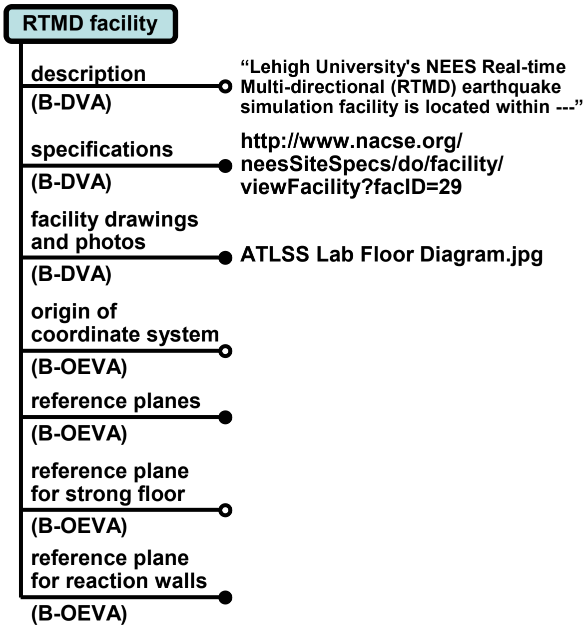
steel property table.doc ···············

Location	σ_y (ksi)		σ_u (ksi)		% elongation at failure	
	Nominal	Exper.	Nominal	Exper.	Expected	Exper.
Column angle long leg	50	66.2	65	94.7	18	24.2
Column angle short leg	50	55.7	65	81.3	18	24.2
Slotted plate	50	66.9	65	91.6	18	23.1
Reinforcing plate	50	59.2	65	85.2	18	25.0
Beam web	50	57.8	65	73.4	18	23.3
Beam flange	50	51.1	65	70.2	18	28.1

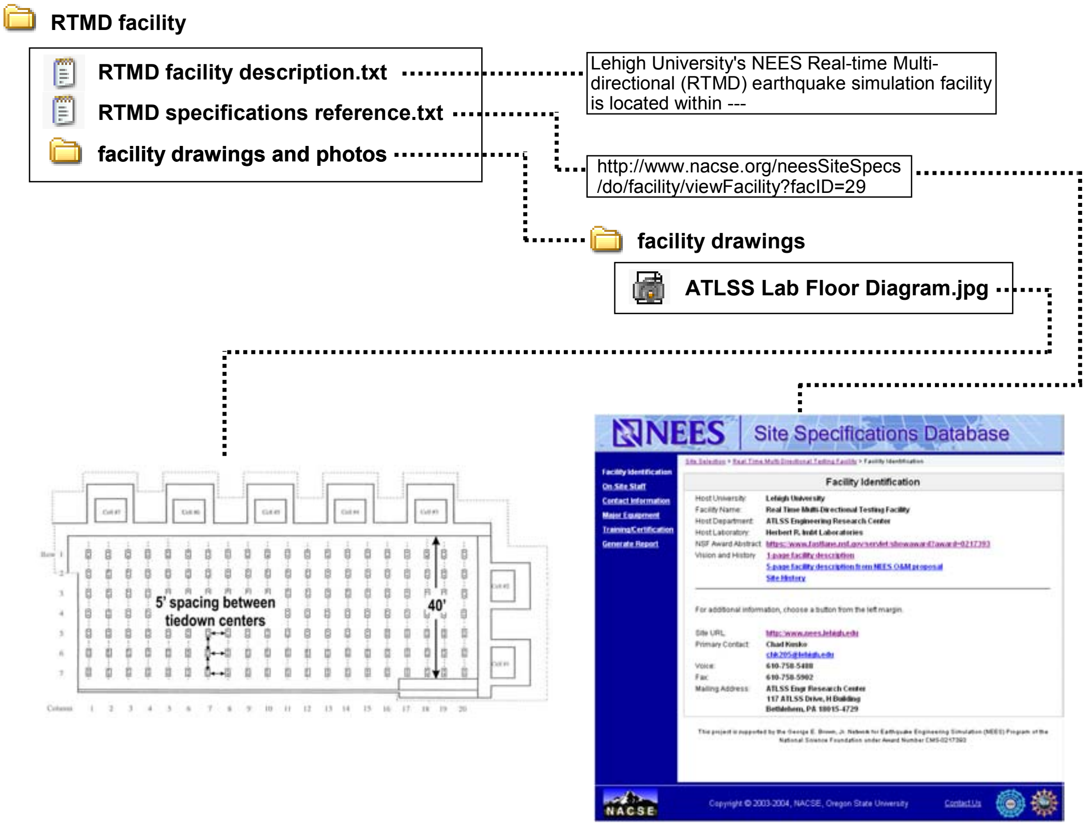
BFFD location description.txt ········ The location of the BFFD can be identified in the setup drawings in test condition 0.

b. System of Folders and Files (continued)

Figure 5.7 Application Example for Specimen Object (continued)



a. Lehigh Model



Site Selection > Real Time Multi Directional Testing Facility > Facility Identification

Facility Identification

Host University: Lehigh University
Facility Name: Real Time Multi-Directional Testing Facility
Host Department: ATLSS Engineering Research Center
Host Laboratory: Herbert R. Imbt Laboratories
NSF Award Abstract: https://www.fastlane.nsf.gov/servlet/showaward?award=0217393
Vision and History: 1-page facility description
5-page facility description from NEES O&M proposal
Site History

For additional information, choose a button from the left margin.

Site URL: http://www.nees.lehigh.edu
Primary Contact: Chad Kusko
chk205@lehigh.edu
Voice: 610-758-5488
Fax: 610-758-5902
Mailing Address: ATLSS Engr Research Center
117 ATLSS Drive, H Building
Bethlehem, PA 18015-4729

This project is supported by the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) Program of the National Science Foundation under Award Number CMS-0217393

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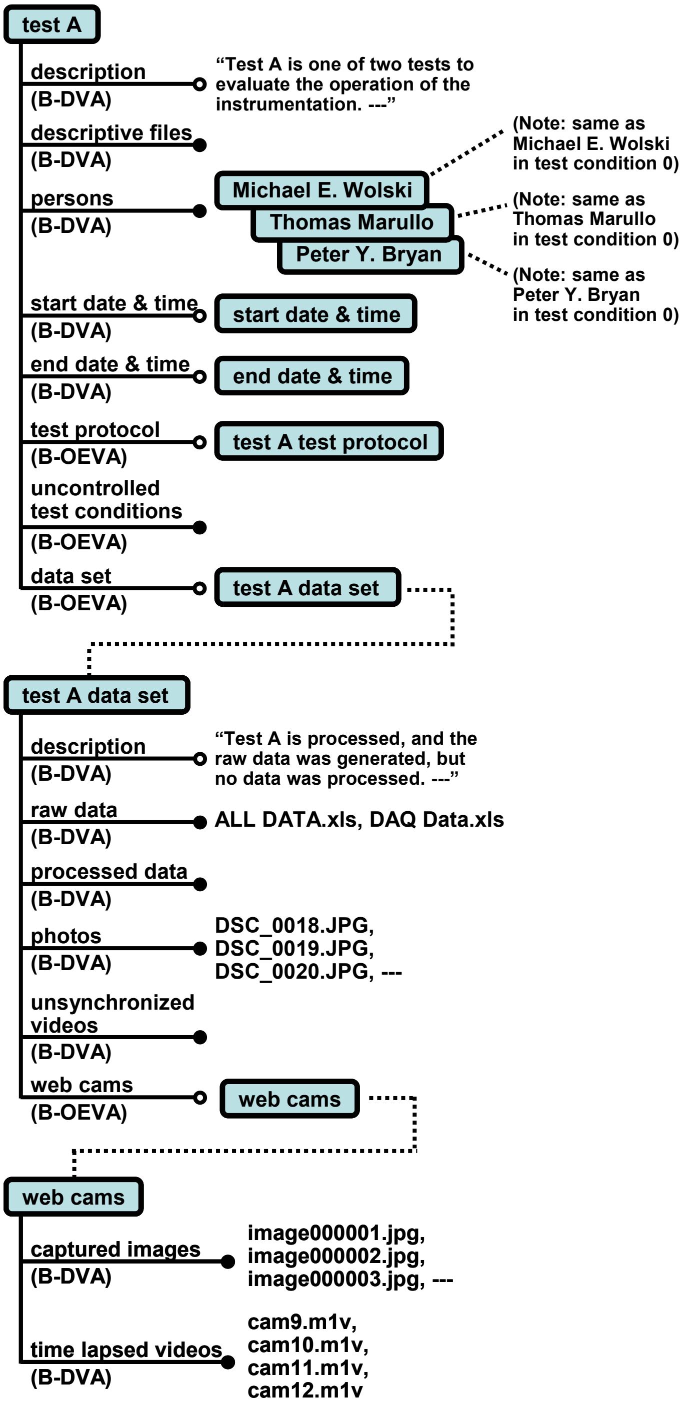
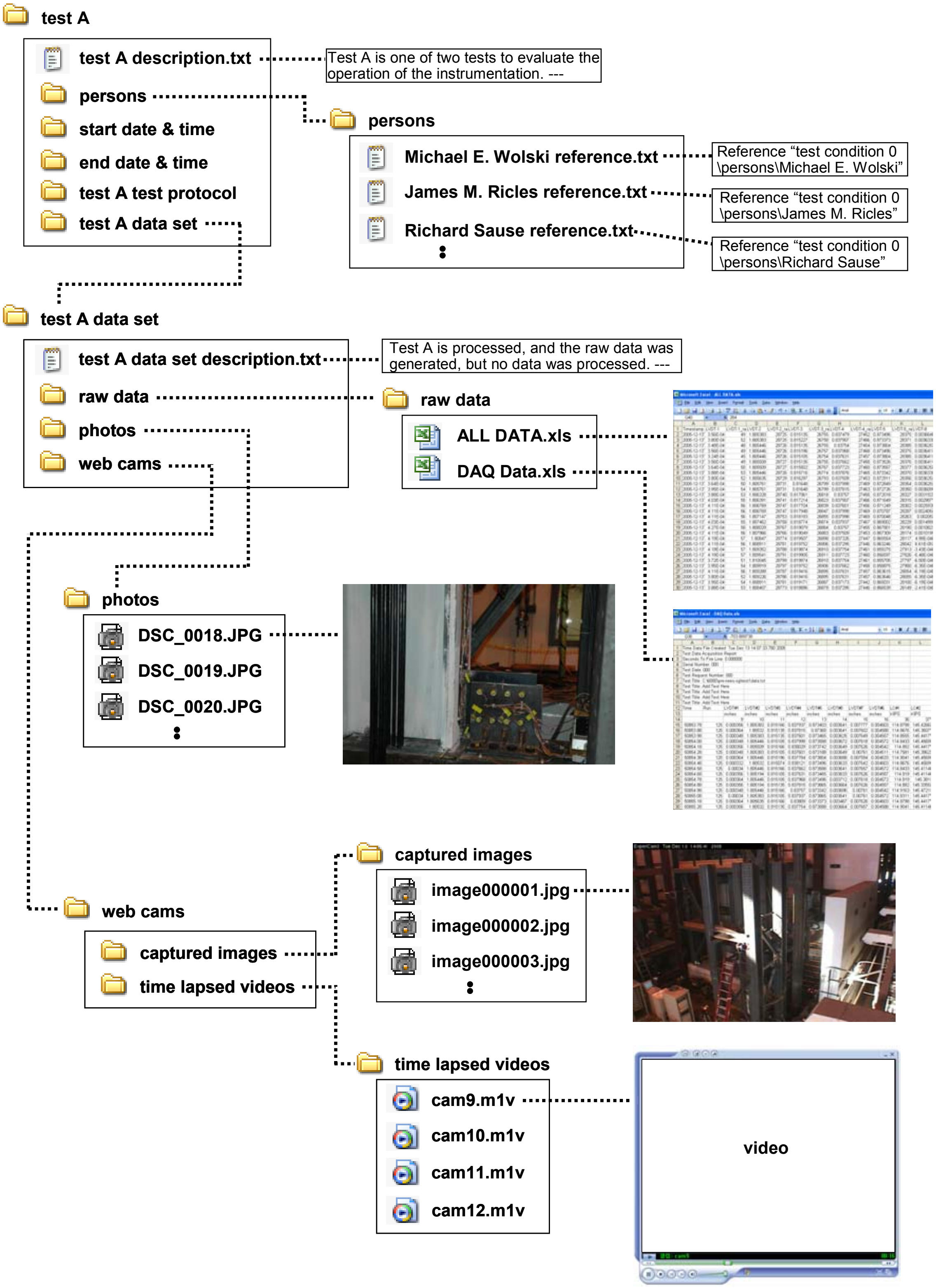
b. System of Folders and Files

Figure 5.8 Application Example for Facility Object



a. Lehigh Model

Figure 5.9 Application Example at Test Class Level



Test A is one of two tests to evaluate the operation of the instrumentation. ---

Reference "test condition 0 \persons\Michael E. Wolski"

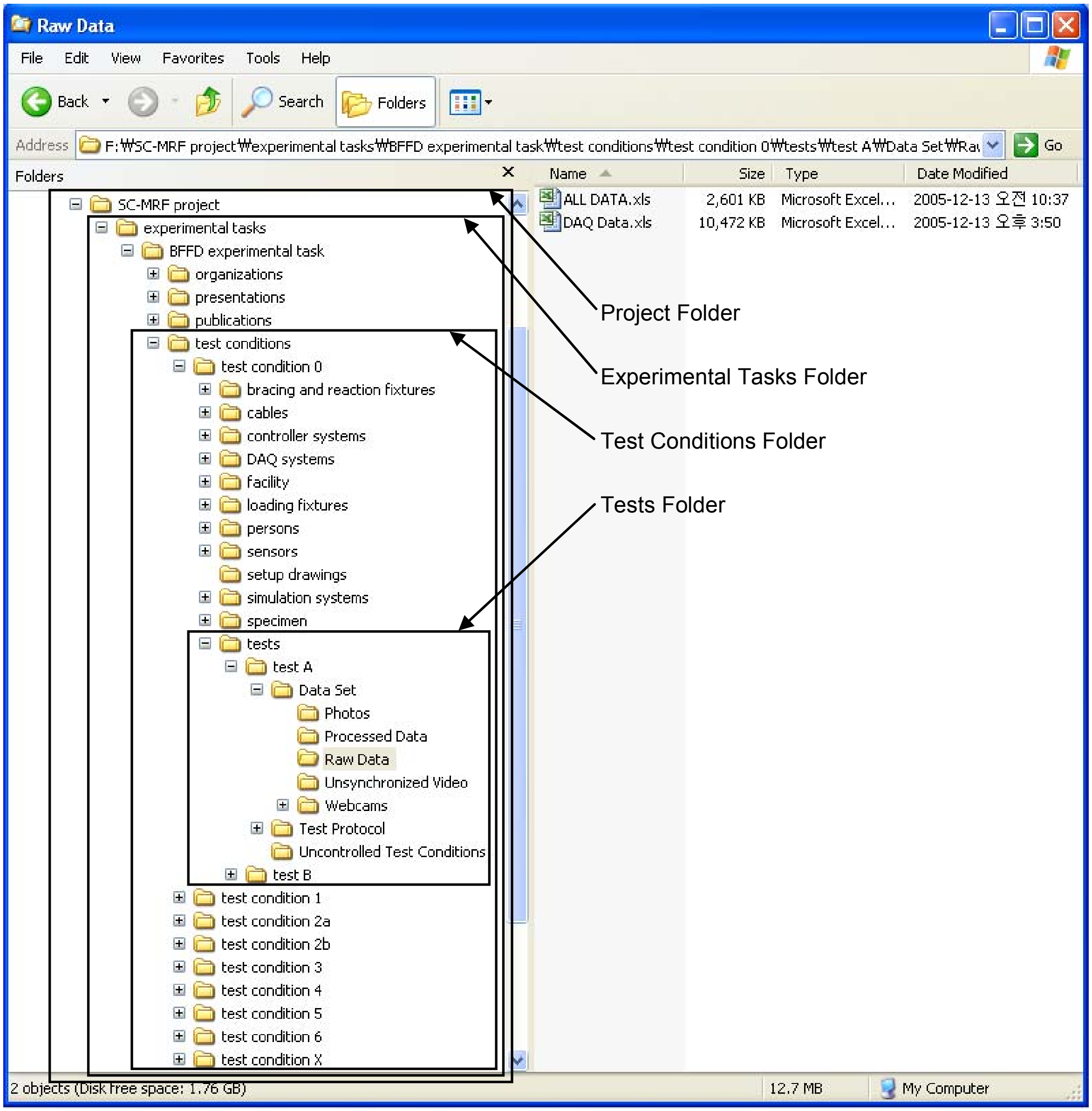
Reference "test condition 0 \persons\James M. Ricles"

Reference "test condition 0 \persons\Richard Sause"

Test A is processed, and the raw data was generated, but no data was processed. ---

b. Current System of Folders and Files

Figure 5.9 Application Example at Test Class Level (continued)



Address: F:₩SC-MRF project₩experimental tasks₩BFFD experimental task₩test conditions₩test condition 0₩tests₩test A₩Data Set₩Ra

Name	Size	Type	Date Modified
ALL DATA.xls	2,601 KB	Microsoft Excel...	2005-12-13 오전 10:37
DAQ Data.xls	10,472 KB	Microsoft Excel...	2005-12-13 오후 3:50

2 objects (Disk free space: 1.76 GB)

Figure 5.10 Folders and Files in Windows Explorer

CHAPTER 6

SUMMARY AND CONCLUSIONS

Information related to large-scale structural experiments is often complicated and stored in various documents, drawings, photos, and other computer-based files. The detailed information related to structural experiments is often difficult to access, share, and use by researchers. A data model is needed to efficiently access, share, and use this information. This report has presented the Lehigh Model for large-scale structural experiments developed at the RTMD facility at the ATLSS Center at Lehigh University. This chapter summarizes the report, reviews the benefits of the Lehigh Model, recommends future research, and provides some concluding remarks.

6.1 Summary

The development of the Lehigh Model began with the thorough review of previous work on data models and databases for structural test data presented in chapter 2. Since previous work has provided either broad descriptions of structural test data or detailed descriptions at a low level, the Lehigh Model is formulated in chapter 3 to address the complexities of structural experiments at a higher level. The classes and attributes of the Lehigh Model are explained in chapter 4, and an illustration of the model using an application example is presented in chapter 5.

Chapter 2 reviews three data models and two databases for structural tests. The Reference NEESgrid Model (Stanford Model) was developed for shake table experiments and the Oregon State Model for tsunami wave basin experiments. The NESScentral Model has been developed and maintained for general categories of structural tests. These models define hierarchies of classes to represent various aspects of the activities that produce test results such as the project, task, event group, and event classes in the Reference NESSgrid Model. The two databases for structural tests, the SAC Design Information Database and the PEER Structural Performance Database, were developed to search mainly for lower level test results for steel structures and concrete structures. These data models and databases can be used to save and retrieve test data. However, the details of the relationships among the test specimens, facilities, and test equipments at a higher level need to be represented in a more complete model. The complexity of information for structural experiments at multiple sites and for hybrid tests should be also carefully considered in a more effective data model for structural experiments.

Chapter 3 describes how the Lehigh Model organizes multiple levels of information for structural experiments. There are four main classes in the hierarchy of classes: the project, experimental task, test condition, and test classes. A project includes a number of experimental tasks. Each experimental task includes a number of test conditions. A test condition is the specific situation under which experiments are conducted. The test condition class includes the specimen and the facility attributes and other equipment attributes. One test condition, including the specimen, facility and equipment, can be used for a number of tests and analyses. By including the facility attribute in the test condition class, the Lehigh Model allows an experimental task to include test conditions at multiple sites.

The details of the classes and attributes of the Lehigh Model are described in chapter 4. The experimental task class generalizes the typical experimental task class and the hybrid experimental task class. As described in the above, the typical experimental task class includes a number of test conditions. In the test condition class, the specimen is composed of components. Various kinds of materials can be used for the components, and the geometry is described using drawings and the locations using drawings or location points and lines. The facility class includes reference planes used for locating the specimen components, the loading fixtures, and the bracing and reaction fixtures. The test class includes the test protocol, uncontrolled test conditions, and data set attributes. For the hybrid experimental task, the attributes of the simulation coordinator, analytical substructures, and physical substructures are defined. Communications among the simulation coordinator, analytical substructures, and physical substructures are represented.

In chapter 5 the Lehigh Model is illustrated using a steel frame connection tests performed at the RTMD facility at Lehigh University. The files generated during the connection test program were organized according to the classes of the Lehigh Model. Implementation of the Lehigh Model as an internet application backed by a database is in progress.

6.2 Benefits of Lehigh Model

The Lehigh Model has been developed to provide an efficient way to describe the information related to structural experiments. Compared with previous data models, the distinctive features and possible benefits of the Lehigh Model are the following:

(1) The project class includes the experimental task class which is the generalization of the typical experimental task and the hybrid experimental task classes. The attributes of the classes are provided, and in particular, the hybrid experimental task class includes the attributes for the simulation coordinator, analytical substructures, and physical substructures. The representation of hybrid experiments using these classes and attributes has been considered.

(2) For the typical experimental task, the test condition class includes the facility attribute and the experimental task class includes test conditions for experiments performed at different sites. The description of multi-site experimental task is thus managed in a direct way.

(3) The hybrid experimental task includes the simulation coordinator at a site, the analytical substructures at multiple sites, and the physical substructures at multiple sites. The use of common attributes enables communication among the simulation coordinator, analytical substructures, and physical substructures to be represented.

(4) The project class includes the analysis tasks attribute and the test condition class includes the analyses attribute. The analysis tasks attribute is for analysis tasks that are not directly related with the experiments but which may be part of the overall project. The analyses attribute is for the analyses of the test specimen under the test conditions. Different levels of analyses are considered.

(5) The test condition class includes the attributes for the specimen, the loading fixtures, and the bracing and reaction fixtures. The specimen class includes a number of components. The loading fixtures are classified into actuators and other loading fixtures.

The attributes for the geometry, material, and location of the specimen components and the fixtures are provided. More detailed information of the setup of a test can be described.

(6) Several ways are provided to describe the setup of a test. The geometry can be described using the setup drawing files and/or the component or fixture drawing files. The materials can have either the nominal or actual values. The locations of specimen components and fixtures can be described using location points and lines at 2-D reference planes or using drawing files.

(7) The test condition class also includes the attributes for acquiring test data and controlling the tests, such as the controller systems and the simulation systems. Theses attributes are intended for describing more precisely how the data is generated and acquired during the test.

(8) The test class includes the uncontrolled test conditions attribute to describe the conditions which are not controlled but may affect the test results.

6.3 Future Research

The Lehigh Model introduced in this report is under continued development. The main classes and attributes of the model are provided, but additional research is required to refine the classes and attributes and to implement the model for practical use. The forthcoming research topics include the following:

(1) The hybrid experimental task needs more classes and attributes to completely describe the complicated relationships which can exist among the simulation coordinator, analytical substructures, and physical substructures.

(2) Research is needed to define the attributes of different kinds of analyses identified in the model.

(3) The validity of the model in this report is discussed using instances of the classes and an arrangement of folders and files for existing test data. The implemented system is expected to show clearly the strength of the model for accessing, sharing, and using information related to structural experiments.

6.4 Concluding Remarks

The advance of information technology has enabled large-scale and complicated structural experiments involving multiple sites. The amount of the information related to these experiments has grown and the details of the information are not easily represented and shared with other potential users. Previous research on data models for structural tests has provided researchers with ways of describing information related to structural tests. The Lehigh Model presented in the report contributes to the development of more comprehensive data models by representing the areas which were not fully addressed by previous data models. It is believed that the model presented in the report will be valuable aid for the researchers who need to represent, access, share, and use information on structural experiments.

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