TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-87/18+457-1		

4. Title and Subtitle	5. Report Date
PRELIMINARY DESIGN OF A TESTING FACILITY TO SUBJECT FULL SCALE PAVEMENT SECTIONS TO STATIC AND CYCLIC LOADING	August 1986
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Mark Dorrance Wickham, B. Frank McCullough, and D. W. Fowler	Research Report 457-1
9. Performing Organization Name and Address	10. Work Unit No.
Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	11. Contract or Grant No. Research Study 3-8-86-457
	13. Type of Report and Period Covered Interim
12. Sponsoring Agency Name and Address	
Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration
Research Study Title: "Thin Bonded Overlay Implementation"

16. Abstract

This study defines the operational and structural requirements that have to be satisfied in order to design a pavement test facility at the Balcones Research Center, a part of The University of Texas at Austin. The facility is to be capable of subjecting pavement sections of up to 12 feet × 24 feet to static and cyclic loading with a maximum applied load of 20 kips. Loading methods, equipment specifications, load frame dynamic and stiffness requirements, and load frame anchorage problems are discussed. Recommended solutions to some of these problems are also discussed.

17. Key Words	18. Distribution Statement
pavement, PCC overlay, laboratory tests, equipment, fatigue, movable structures, post-tensioned concrete, load frames, anchorages	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	70	

Form DOT F 1700.7 (8-69)

PRELIMINARY DESIGN OF A TESTING FACILITY TO SUBJECT FULL SCALE PAVEMENT SCECTIONS TO STATIC AND CYCLIC LOADING

by

Mark Dorrance Wickham
B. Frank McCullough
D. W. Fowler

Research Report Number 457-1

Thin Bonded Overlay Implementation

Research Project 3-8-86-457

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

August 1986

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This is the first report produced Research Study 457, "Thin Bonded Overlay Implementation." The long range goals of this project are to implement design and construction procedures of overlays developed in this project and previous projects and to observe the overlaid pavement sections for some years on a continuing basis. A component of this project is to investigate methods of testing full scale overlaid pavements or sections of pavements. These tests would be accelerated cyclic (fatigue) loading to observe the structural behavior and the modes of failure of these specimens.

This report is a preliminary design and feasibility study of a testing facility to subject full scale pavement sections to static and cyclic loading. This first investigation of the subject primarily defines the design problem and describes possible solutions. Some of the design parameters that are discussed are description of the test specimen, method of applying loads, required roadbed, required test equipment, load frame configurations, and anchorage concepts for the load frame.

Many persons have contributed significantly to this work, and the authors are grateful to them all. Special mention needs to be made of Dr. Ned Burns for suggesting the concept of post-tensioned anchorage systems, to Dr. Kenneth Stokoe II for invaluable geotechnical advice, and to Dr. Karl Frank and Dr. Richard Klingner for advice on the structural design of the load frame. Thanks are also due to Karen Reilley, Janette Garcia, Bob Gloyd, Ray Buvia, James Stewart, Dave Whitney, and Lyn Gabbert for their technical assistance and support.

LIST OF REPORTS

Report 457-1, "Preliminary Design of a Testing Facility to Subject Full Scale Pavement Sections to Static and Cyclic Loading," by Mark Dorrance Wickham, Dr. B. Frank McCullough, and Dr. D. W. Fowler, defines the problems and presents possible solutions for the design of a testing facility to cyclicly load full scale pavement sections. August 1986.

ABSTRACT

This study defines the operational and structural requirements that have to be satisfied in order to design a pavement test facility at the Balcones Research Center, a part of The University of Texas at Austin. The facility is to be capable of subjecting pavement sections of up to 12 feet x 24 feet to static and cyclic loading with a maximum applied load of 20 kips. Loading methods, equipment specifications, load frame dynamic and stiffness requirements, and load frame anchorage problems are discussed. Recommended solutions to some of these problems are also discussed.

KEYWORDS: Pavement, PCC overlay, Laboratory tests, Equipment, Fatigue, Movable structures, Post-tensioned concrete, Load frames, Anchorages

SUMMARY

An investigation was undertaken to determine the work required and approximate cost of constructing a test facility at Balcones Research Center at The University of Texas at Austin, which could load full scale pavement sections of at least one normal lane width in a way that would simulate deterioration due to fatigue. The study examined methods of loading the pavement to simulate truck traffic, possible locations for the facility, equipment and utilities that would be required at the site, load frame configurations, and anchorage of the load frame.

The investigation was continued until a reasonable estimate of the work required and an approximate cost of construction could be determined. The project was much more involved than first envisioned, and the cost of the project was estimated to be greater than $59,000.

IMPLEMENTATION STATEMENT

This study provides the basis for the design of a pavement testing facility. The facility is capable of subjecting 12–foot x 24–foot pavement sections to static or fatigue loading. The design and construction of the facility have the following primary requirements which need in depth investigation:

(1) The roadbed must be representative of typical highway conditions. This may be difficult to model at Balcones Research Center due to the stiff limestone bedrock.

(2) To perform accelerated fatigue testing at loading rates of 3 to 5 cycles per second, the cumulative deflections of the specimen, load frame, and anchorage have to be less than 0.30 inches.

(3) The load frame must be very stiff, but must also be light enough to allow movement of the loading mechanism to various locations on the pavement.

(4) The facility requires a roadbed to support the pavement sections and by definition of the problem, the sections are very large. These conditions require that the facility be located out of doors exposed to the environment. Provisions must be made to properly protect the loading and data gathering equipment from weather.

(5) Anchorage of the load frame to the soil is probably going to be the most difficult task of the project. The anchorage must be rigid so that the deflection capacity of the hydraulic equipment will not be exceeded. Fatigue loading will have a tendency to loosen typical anchorages. Post-tensioned concrete piers may be a potential solution.

TABLE OF CONTENTS

CHAPTER 3. INITIAL SPECIFICATIONS AND CONCEPTUAL LAYOUT OF FACILITY

CHAPTER 4. ROADBED REQUIREMENTS

CHAPTER 5. HYDRAULIC AND TEST EQUIPMENT

CHAPTER 6. LOAD FRAME

CHAPTER 7. ANCHORAGE OF THE LOAD FRAME

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 1. INTRODUCTION

This report summarizes an investigation to determine the work required and approximate cost of constructing a test facility at Balcones Research Center at the University of Texas at Austin, which could load full scale pavement sections of a least one normal lane width in a way that would simulate fatigue deterioration due to truck traffic.

BACKGROUND

This investigation was originally funded under CTR Project 357 Thin Bonded Concrete Overlay and continued under CTR Project 457 Thin Bonded Overlay Implementation. The objectives of these projects were to observe the behavior of thin bonded concrete overlay pavements subjected to heavy truck traffic, determine construction methods for placing the overlays, and to implement these methods. (Refs 4 and 5) One goal of these projects was to build a test facility that could subject full scale pavement sections to load conditions that would simulate heavy truck traffic.

To date, the only pavement fatigue tests at the university have been done on half-scale pavement models. Scaling down certain properties and dimensions of full scale pavements, such as the size, material properties, and placement of reinforcement bar, mix proportioning of the concrete, and modeling of joints has been difficult. A facility that could perform fatigue test on full size pavement sections would eliminate having to account for scaling effects.

Currently, studies of the behavior of full scale pavement sections had to be done on in service roads. These tests were field observations of pavement deterioration, which were very time consuming. Most well designed and constructed pavements take years to deteriorate. Another problem with extended field observations is that it is difficult to separate different causes of deterioration such as fatigue, chemical attack, and erosion of the roadbed. It is also very dangerous to work around a highway opened to traffic. With the proper equipment, loading conditions simulating 20 years of heavy traffic can be applied to pavement sections in a test bay in two weeks to two months.

OBJECTIVES

The objectives of this study were:

(1) Define the desired operational capabilities of the test facility.

(2) Determine the critical design tasks that influence the feasibility and cost of the facility.

(3) Make a preliminary analysis of each task to determine its approximate cost.

(4) Document the results of Objectives 1 through 3 along with any discussion or design recommendations which would be helpful.

SCOPE

This report discusses the operational specifications of the testing bay, problems associated with its design and construction, and describes some possible solutions for these problems. The report is in a format which can be used in the future as a guide for the design of the facility.

Chapter 2 is a description of the proposed testing program for CTR Project 457 that would subject concrete pavement sections to fatigue loading. The design of this facility is primarily based on the ability to load these proposed test specimens. This chapter includes a description of how the specimens are loaded, how this loading method simulates truck traffic, and the how the size of the specimen should be determined.

A conceptual design of a test facility to perform the tests discussed in Chapter 2 is described in Chapter 3. This design is divided into four components; site location and roadbed material, required hydraulic equipment, load frame design, and frame anchorage. These components are discussed in more detail in later chapters.

As mentioned earlier, the location of the test area would be at Balcones Research Center. Chapter 4 discusses two specific locations at BRC that may be adequate. Requirements of the roadbed that have to be investigated in the future are also described.

The specimens are to be loaded by a hydraulic ram positioned over the pavement by an adjustable portal frame. Chapter 5 describes the operational requirements and limitations of the hydraulic equipment needed. Chapter 6 shows two portal frame configurations, which could be used. Finally, Chapter 7 describes the problems of anchoring the load frame and the possible use of dead weight anchors or post-tensioned concrete piers.

CHAPTER 2. DESCRIPTION OF FULL SCALE TEST OF CTR PROJECT 457

The purpose of the full scale testing program under CTR Project 457 was to determine the mode of failure of thin bonded overlay concrete pavements, the effect of casting the overlay during different states of distress of the base slab, and to determine the definition of 'no serviceable life' for pavements as well as finding ways to measure it (Refs 4 and 5). This experiment was to include cyclic loading of three identical slabs each representing a single lane of a continuously reinforced portland cement concrete highway. A localized area of the first specimen (Slab 1) would be fatigue loaded until that area of the slab (defined as the test area) had zero serviceable life. The test area of a second specimen (Slab 2) would be subjected to the same loading pattern and intensity as that of Slab 1, but only for 30 percent of the number of cycles as that of Slab 1. Slab 3 would be subjected to the same loading method at that of Slab 2, but only loaded with 60 percent of the number of cycles required to fatigue Slab 1. All three slabs would then be overlaid with a 2-inch layer of portland cement concrete, reinforced with deformed steel wire fabric. These three overlaid specimens would then be loaded at the same location as before. Cyclic loading would continue until the overlaid test area had no remaining serviceable life. Figure 2.1 shows a schematic of the testing procedure of a specimen.

Although it was designed for testing a bonded overlay, it should be emphasized that the test facility described in this report can be used for testing many types of pavements in many different studies. The facility can be used to apply cyclic loads or static loads.

MODELING OF LOADS

Pavements are deteriorated by moving wheel loads which quickly stresses each point it travels over. The wheel load remains constant, but moves from point to point along a path uniformly stressing all points of contact (assuming the pavement is homogeneous). For a given point along the wheel path, the wheel load can be approximated as a sinusoidal pulse. To complicate the problem, all wheel loads do not follow the same path. Over time, these movement characteristics create relatively uniformly deteriorated strips of pavement which are parallel to the movement of traffic.

Practically and economically, it would be impossible to perfectly model this type of loading. Due to the expense of test equipment, the proposed test facility is limited to only one

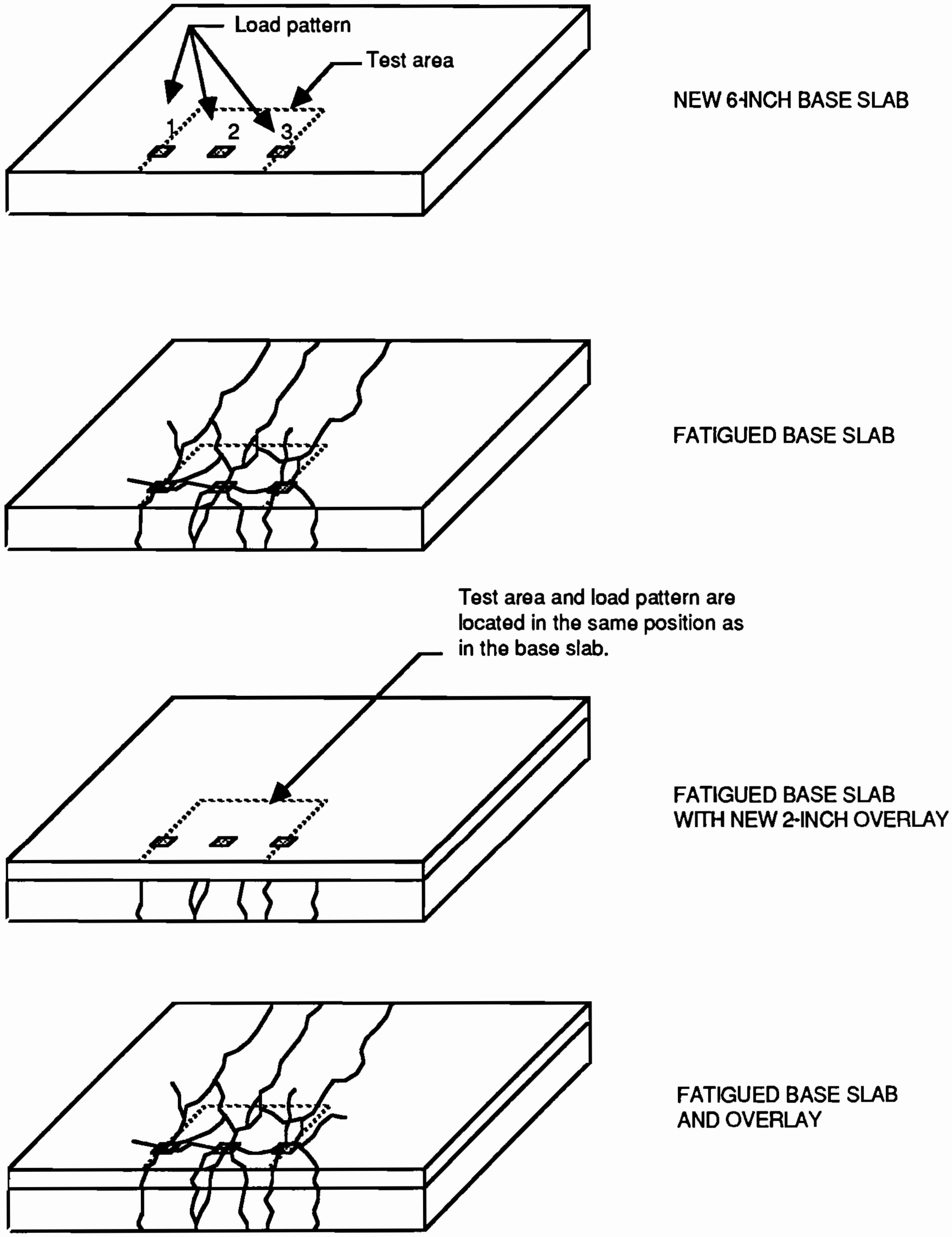


Fig 2.1. Testing procedure showing the testing area and load pattern.

load device, but the load point may be placed in multiple locations on the specimen. Pavement deterioration has to be modeled using discrete load points. It is proposed that if an area of pavement is loaded at several predetermined points and in a specific manner, the deterioration resulting from the set of concentrated loads will be similar to that caused by a known amount of truck traffic over the same area.

Based on this proposed method of modeling pavement fatigue over a specified area by predetermined loads applied in a specific manner, the terms of "test area" and "load pattern" are defined.

Test Area

To test continuously reinforced concrete pavements, large specimens are generally required. The "test area" is a local area within the specimen which behaves as if the pavement did not have a finite length. The remainder of the specimen provides a continuous boundary so that the effects of the finite specimen size does not effect the test area, unless edge effects are desired (such as the boundary along the shoulder of the road). The "test area" (approximately 3 feet x 3 feet) for Slabs 1, 2, and 3 in CTR Project 457 would be loaded until that entire area deteriorated to the condition specified for each specimen.

Loading Pattern

The loading pattern is a set of points on the slab that have to be loaded in a specified order to uniformly fatigue the test area. The size of the test area is interdependent on the loading pattern. As the test area is increased, more load points are required to deteriorate the area, which will extend the duration of the test. For example, if a load pattern of five points is loaded at five cycles per second and. If the average number of cycles to the load each point is 3,000,000 it would take 8 days to load just one point and 40 days to load five points. Testing of the three base slabs and the overlays would take almost eight months, and this time does not include casting and removing the specimens nor delays due to equipment failure or weather.

Very little work has been done to analytically determine the optimal load patterns, but a method involving the use of program ELSYM5 (Ref 1) to model the test specimens is recommended. With this program, the stress gradients of various load patterns can be determined. In Fig 2.2 a load pattern of three points is shown. The load area, determined by the

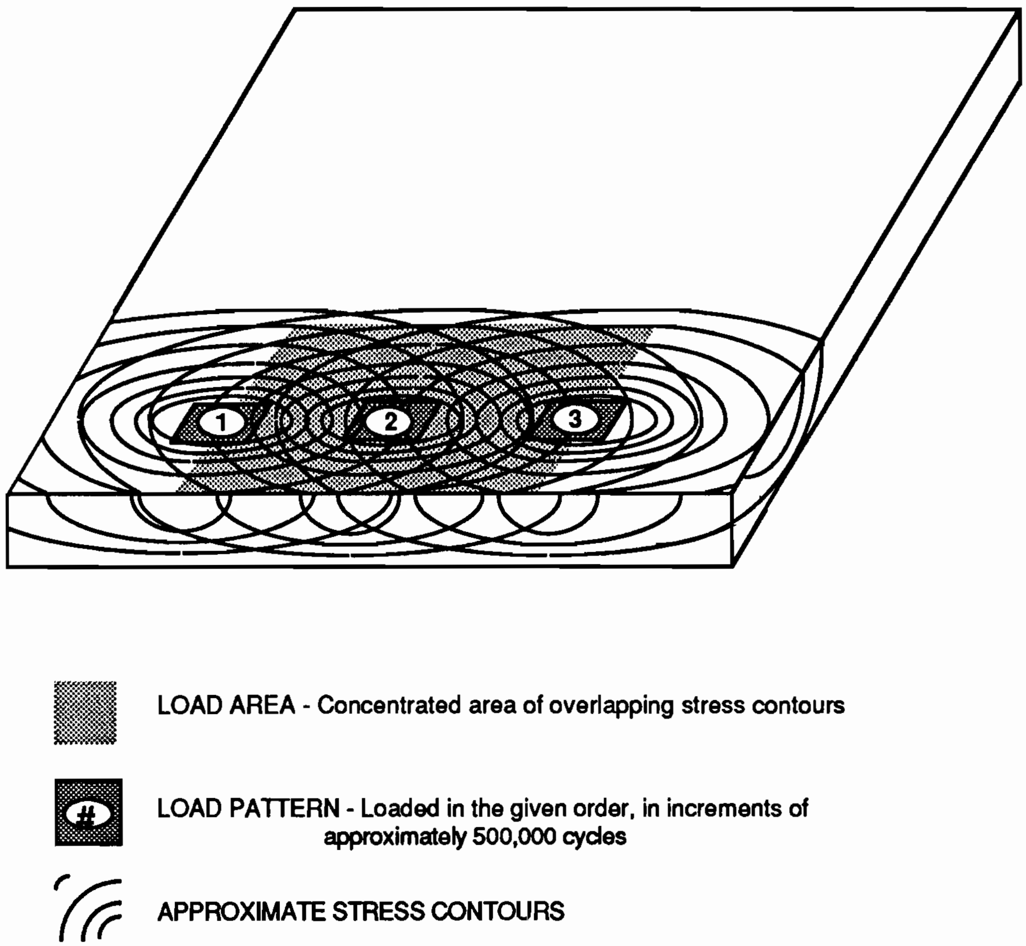


Fig 2.2. Proposed loading pattern with an assumed test area which is determined by the density of overlapping stress contour lines.

conceptual overlapping stress regions are also shown. The three point loading pattern is recommended at this time, since fewer points would severely limit the load area and larger number of load points dramatically increases the duration of testing. ELSYM5 should be used to determine the optimal distance between load points.

Load

Fatigue life was based on the number of 18-kip equivalent single-axle loads (9 kips for each wheel). This load would be applied to the pavement by a hydraulic actuator (ram) which is a part of a closed loop loading system(see Chapter 4). The frequency of loading is assumed to be three to five cycles per second, depending on the stroke of the actuator (assumed to be less than 0.2 inches), the size of the actuator and the capacity of the pump. The load would be applied to the surface of the specimen through a steel plate with a section of tire tread attached to the underside of the plate. This plate would have a surface area of 120 square inches producing an applied load of 75 psi for a 9--kip load.

Length of the Test Specimens

The proposed width of the test pavement is 12 feet, but this length is tentative until more analysis is done. Twelve feet would be the minimum length since anything smaller would make the length less than the width. Keeping the specimens as short as possible needs to be emphasized so as to make the casting and the removal of each test specimen easier.

One method to determine the minimum slab length is to calculate the size and shape of the deflection basin of an infinitely long pavement loaded by a single concentrated load and then calculate the deflection basin of finite length slabs with the same load condition. The slab with the smallest length and yet has a deflection basin equal to that of the infinite length slab is the optimum size specimen.

This method should be used to find the required length of the specimens with the lowest and highest flexural stiffnesses. Calculating these required lengths will act as a design envelope. The longest length calculated from the two conditions should be used for all specimens to maintain uniformity. Program SLAB49 (Ref 6) can be used to model finite length pavement sections.

In addition, the length of the test specimen has to be long enough to cause shrinkage cracking across the width. The edge of the center load point is to be adjoining a transverse crack in the slab to achieve the fastest rate of deterioration. If transverse shrinkage cracks do not occur, a method of producing a crack has to be determined.

MATERIAL SPECIFICATIONS

These specifications describe the proportions of the concrete mixes and the placement of the reinforcement steel.

Base Slab

The base slab is to be 8 inches thick, the same thickness as most CRCP in Texas. The specifications of the base slab are determined using the construction plans of the Loop 610 pavement and a reference map (Ref 8), which shows some of the specifications used for sections of the highway. The proposed concrete specifications are:

(1) Type I cement, 5.0 sacks/yd^3,
(2) 3/4 inch maximum aggregate, 1335 lb/yd^3,
(3) sand, 1320 lb/yd^3,
(4) air entraining admixture, 0.5 ounce/100 lb of concrete,
(5) 2 to 4 inch slump, and
(6) 3 to 6 percent air content.

These mix proportions are also consistent with the CTR Project 457 half-scale testing program. The steel reinforcement consists of no. 5 bars, running longitudinally, spaced 6–1/2 inches apart (area of steel/area of concrete = 0.5) and no. 4 bars, running transversely, spaced 30 inches apart. All reinforcing bars are to have a yield strength of 60 ksi.

Overlay

The overlay thickness is to be 2 inches thick. This is the suggested thickness in the original proposal to the highway department. (Ref 4) Although the Houston overlay project proposed using a 4 -inch overlay, the thinner layer is chosen because the time required to fatigue the thicker overlay to "no existing life" is feared to take too long. The mix design is based on the highway specifications for Houston overlay project (Ref 10) which is also consistent with the mix design of the half-scale thin bonded concrete overlay project. The proposed concrete mix properties are

(1) Type I cement, 7 sacks/yd^3,
(2) 3/4 in. maximum aggregate, 1335 lb/yd^3,
(3) sand, 1320 lb/yd^3,
(4) air entraining admixture, 0.5 ounce/100 lb of concrete,
(5) 4.5 gallons of water per sack of cement, and
(6) 4 to 6 percent air content.

The overlay is to be reinforced with a deformed wire mesh supplied by Ivy Steel & Wire Co., P.O. Box 15633 Houston, TX 77220. The mesh was to maintain the same A_s/A_c (area of steel/ area of concrete) ratio in the longitudinal direction as that of the base slab. The proposed deformed wire mesh was the to have the same spacing between wires as the Loop 610 overlay project. With these assumptions, the mesh was chosen to be 6 inches x 12 inches - D8 x D4.

INTERFACE BETWEEN LAYERS

In the Houston overlay project, the surface of the base pavement is scarified by rotomilling. (Ref 10) It is proposed that the surface of the base test slabs be roughened immediately after casting in a manner which would produce a surface similar to that produced by rotomilling. The advantage of this procedure is that a rotomilling machine would not have to be brought to the test sight prior to casting an overlay. If the use of a rotomiller could be arranged, (it would only be needed three times and each time would only be for a day) it would be the better method of preparing the surface of the specimens because roughening the surface of the slab immediately after casting makes observation of the cracking patterns of the base slab during loading almost impossible. This was realized during the CTR Project 457 half-scale model test. Observing the crack growth while loading the half-scale slabs is very difficult because the cracks generally followed along the valleys of the roughened surface. This made the cracks propagate in odd directions and the shadows created by the roughened surface made small to medium size cracks almost impossible to see.

If it is decided that the base slab is to be roughened during casting, then a careful investigation of the condition of a rotomilled surface needs to be made. From these observations, surface specifications and a procedure for preparing a wet surface can be made.

CHAPTER 3. INITIAL SPECIFICATIONS AND CONCEPTUAL LAYOUT OF FACILITY

As described in CTR Project 357 proposal to SDHPT (Refs 4 and 5), the initial objective of the facility was to test pavement sections at least one lane wide, have the facility built on or near the CTR test facility at Balcones Research Center, and use a hydraulic loading system similar to the that used for the half-scale model tests in previous CTR projects. Starting with these concepts and determining the specifications required to perform the tests described in Chapter 2, a conceptual layout of the new test facility was developed. Once the conceptual layout was agreed upon, the design of the facility was divided into four categories; roadbed, hydraulic and instrumentation equipment, load frame, and load frame anchorage. Each topic was investigated to a point where a reasonable cost estimate could be made.

This chapter describes the initial operational specifications and the conceptual layout of the facility. Chapters 4 through 7 describe the individual investigation and recommendations concerning the roadbed, hydraulic and instrumentation equipment, load frame, and load frame anchorage.

FACILITY SPECIFICATIONS

To perform the experiments described in the previous chapter and similar pavement experiments at Balcones Research Center, the following specifications were suggested:

(1) The maximum specimen sizes would be 24 feet long and 12 feet wide.

(2) Loads were to be applied by a single hydraulic actuator suspended over the specimen.

(3) The actuator could be placed any where within a 12–foot x 12–foot area over the specimen.

(4) The roadbed would be designed such that Dynaflect readings from specimens, described in Chapter 2 which are supported by this roadbed, would produce similar deflection results as that of sections of the 610 Loop in Houston, Texas, in the same state of distress.

(5) All hydraulic and electrical equipment would be properly protected from the environment.

(6) The facility would be designed to be used continually year round.

(7) Maximum applied loads exerted by the actuator would not exceed 30 kips for static loading and 20 kips for cyclic loading.

(8) The facility had to be accessible to heavy equipment such as forklifts to move the specimens and concrete trucks to place specimens.

CONCEPTUAL ARRANGEMENT

The proposed facility consists of a fill mound upon which the pavement sections can be placed or cast. Loads would be applied to the specimen by a hydraulic actuator suspended over the pavement by a movable portal frame. This frame would span across the width of the specimen and be anchored to concrete beam foundations, one on each side of the specimen, as shown in Figs 3.1 and 3.2.

The fill mound built for CTR Project 355 (Ref 11) will be used as the roadbed if it will produce adequate Dynaflect results. If this roadbed is inadequate and cannot be changed without affecting other tests on the mound, then a smaller fill mound could be built next to the existing mound. Either site would allow the use of an existing power supply and climate controlled shed for equipment storage.

The actuator powered by a closed loop hydraulic system, can be hung from any point along the lower flange of the horizontal beam of the portal frame. The equipment needed to power the actuator would be housed in the existing storeroom and in a proposed adjoining shed.

The steel portal frame which supports the actuator over the specimen, spans across the width of the specimen. Ends of the horizontal beam are bolted to a columns so that the height of the beam above the slab can be adjusted. These columns are anchored into special channels embedded into parallel concrete beams, one beam on either side of the specimen. Channels allow the load frame to be bolted anywhere along the length of the beams. Post-tensioned concrete piers drilled deep into the limestone bedrock anchor the concrete beams.

This system allows a large specimen to be placed on a roadbed similar to typical highway roadbeds. The specimen can be loaded over any point within a 12–foot x 12–foot area. Also, a very stiff foundation is provided to anchor the load frame reaction.

Environmental protection and utilities will have to be provided for equipment such as the controller for the hydraulic loading system, any data acquisition equipment, and the

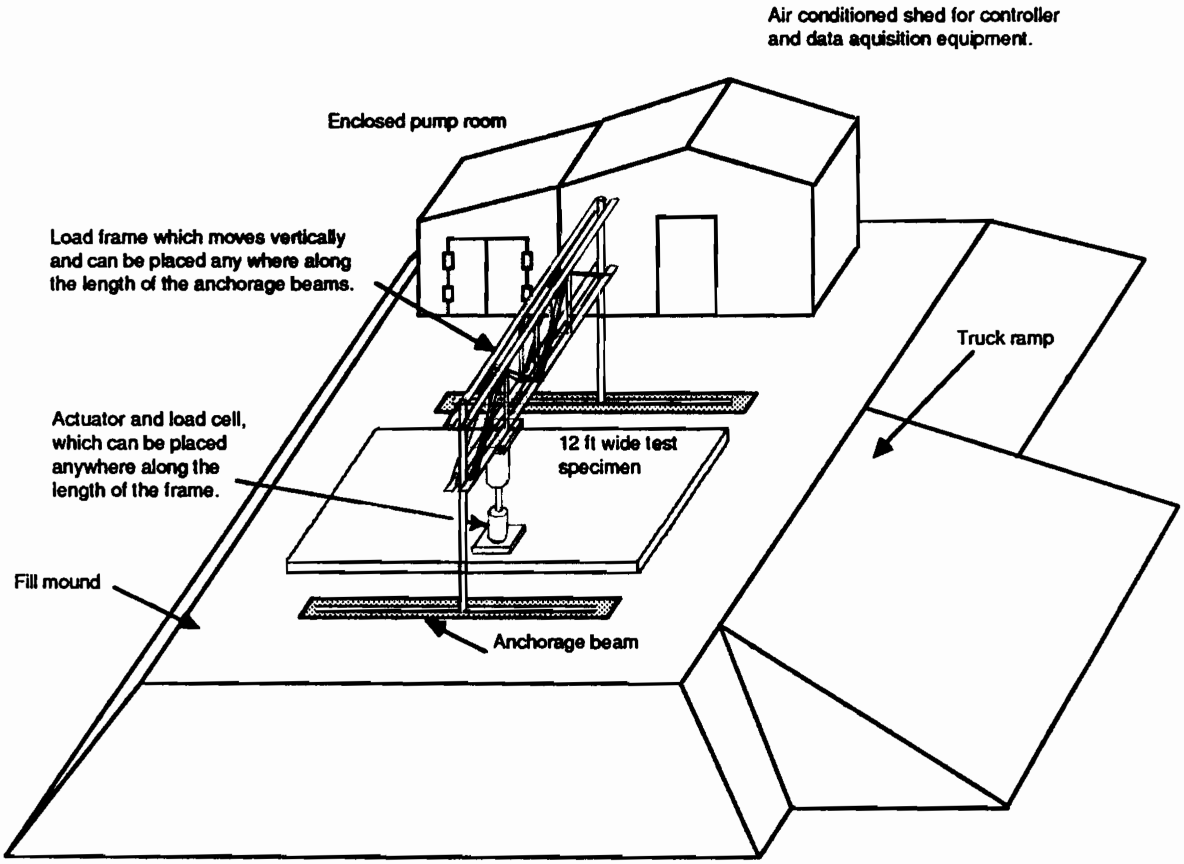


Fig 3.1. Sketch of the proposed test facility.

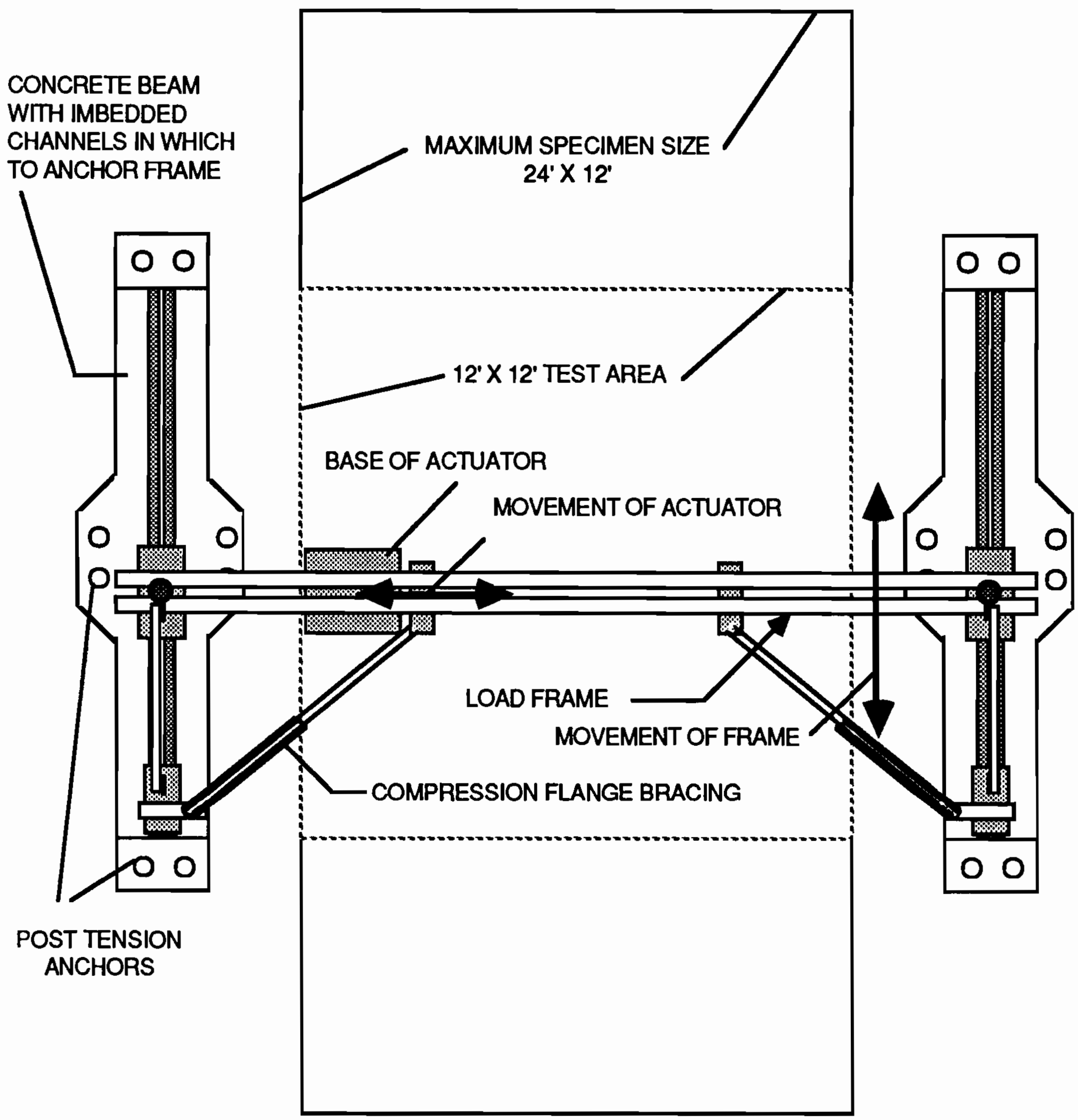


Fig 3.2. Plan of the proposed load frame and test area.

hydraulic pump. The hydraulic pump, in particular, requires a large amount of electricity and water as well as a separate storage building due to the noise it produces.

A preliminary estimate of the cost to construct this facility is about $60,000. (Ref 14) The costs for the major components discussed in this paper are listed in Table 3.1.

TABLE 3.1 COST ESTIMATE OF THE PROPOSED TEST FACILITY

Roadbed Construction	$ 7,900.
Hydraulic and Electrical Equipment	26,300.
Load Frame Fabrication	8,500.
Load Frame Anchorage	13,800.
Total	$ 59,000.

CHAPTER 4. ROADBED REQUIREMENTS

Roadbed provides a uniform support for the test slab. For typical pavement specimens, the roadbed is to simulate the stiffness of the Loop 610 roadbed. Very little work has been done in determining how to achieve the desired soil properties. Originally, a section of the fill mound built in CTR Project 355 (Ref 6) was to be used, but after some conversations with the geotechnical engineer who assisted in the design of the mound, Dr. Stokoe, it was feared that the fill mound would be too stiff for fatigue testing. A slab supported by a rigid roadbed would exhibit local punching shear or crushing type failure when subjected to concentrated loading. More flexibility is required to allow the material surrounding the load point to help resist the load in bending.

PROPOSED ALTERNATE FILL MOUND SITE

For projected cost purposes and in the event the existing fill mound is found to be unacceptable, a conceptual configuration of an alternate fill mound was made. This mound was assumed to be of clay approximately four to five feet deep and with a side slope of 1 to 4. A top surface area of 35 feet x 35 feet was the assumed working surface. The proposed fill mound would adjoin the existing CTR Project 355 fill mound on its west side as close to the work shed as possible. Figure 4.1 shows the arrangement of the proposed site relative to the existing site.

The cost of placing and grading the soil needed for this alternate site was $7,900. The work would be done by the Balcones Physical Plant and the soil would come from unused land at BRC. If the soil has to be brought from outside the university, the price of constructing the mound could double.

WORK TO BE DONE

During the conceptual design of the fill mound several problems were found, most of which have yet to be solved. Solutions for the following problems still have to be found.

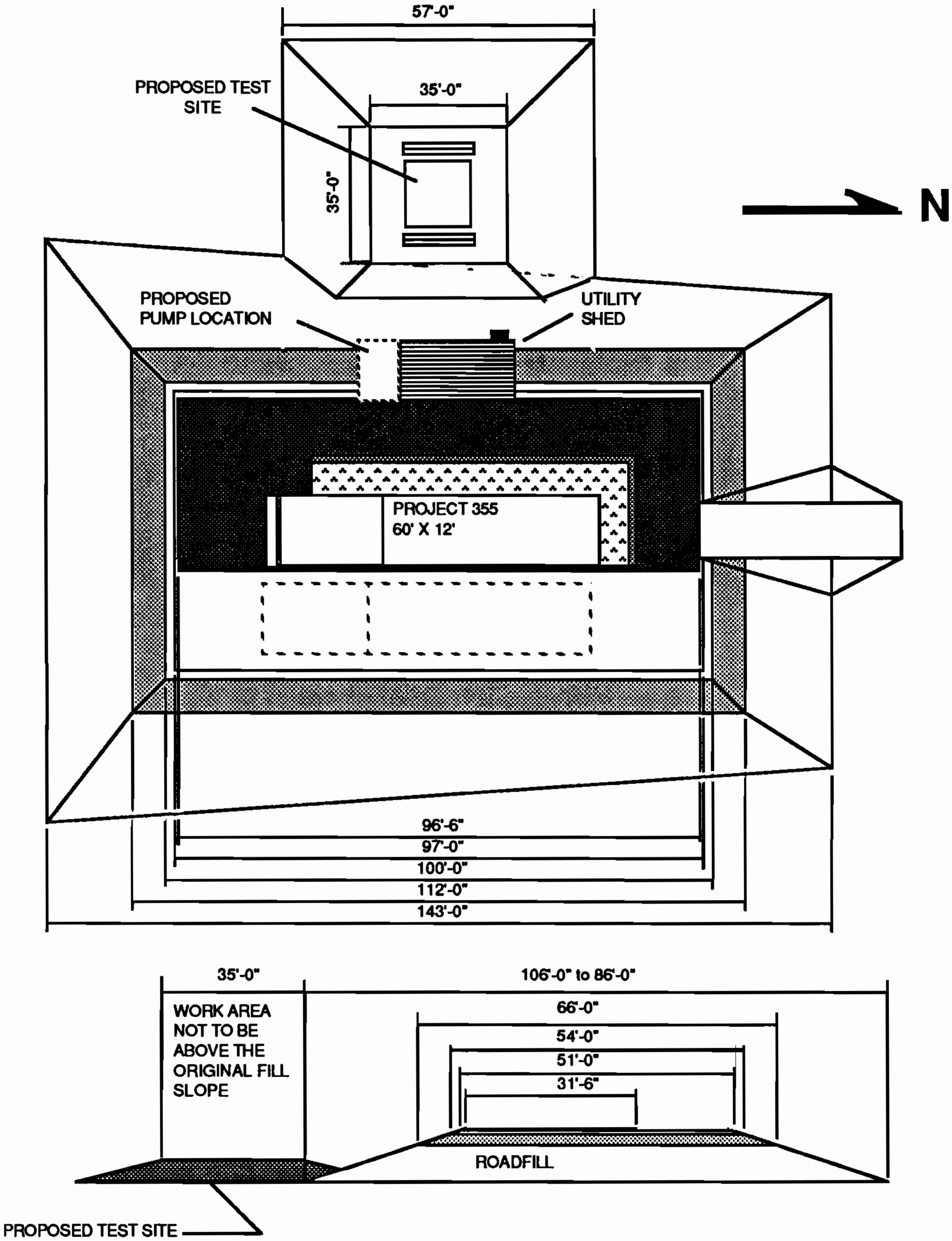


Fig 4.1. Existing CTR fill mound and the proposed test facility.

(1) A material composition that will give the desired deformation characteristics under loading has to be found.

(2) The slope of the mound must be stable to prevent erosion due to weather and traffic.

(3) The stiffness of the soil cannot change significantly; e.g., changes due to time, humidity, or water content.

(4) The fill mound may require a sand or gravel drainage system, to prevent high water content of the soil.

(5) The top of the mound has to be accessible to vehicles, especially concrete trucks and forklifts by constructing a ramp up on side of the fill mound.

(6) The failure of the soil by applied loads through the test specimen or the anchorage beams has to be prevented. (discussed further in Chapter 6).

(7) The assumed top working surface space is 35 feet x 35 feet; the adequacy of the size of this area has to be investigated.

CHAPTER 5. HYDRAULIC AND TEST EQUIPMENT

Equipment required to apply load to the specimen and instruments and gauges required to measure the deterioration of the specimen are the state of the art and expensive. The proposed loading system is proposed to be a closed loop hydraulic loading system. The data acquisition system for measuring deflection and strain of the test specimen has yet to be fully investigated. This system would have to have to be capable of recording peak deflections and strains during cyclic loading.

Some of the required equipment is owned by the Department of Civil Engineering and the CTR Department. Unfortunately, the availability of this equipment is questionable because once the equipment is taken out to the test site, it would be difficult for other university projects to share it. So, for the facility to have the required equipment, most of it will have to be purchased and eventually all the borrowed equipment will have to be returned requiring new equipment to replace it.

Special provisions to accommodate many of the electrical and hydraulic components will also have to be made. Factors such as insulation from severe temperatures, humidity, and dust have to be taken into account. Electricity, water, other fluids, and materials required to operate and maintain the equipment will have to be supplied.

CLOSED LOOP HYDRAULIC LOADING SYSTEM

A closed loop hydraulic loading system provides one of the best means of providing controlled predetermined loads to a specimen. With this proposed system, static load of up to 30 kips can be applied and sinusoidal cyclic loads can be applied as fast as five cycles per second. This system has the following components: (a) hydraulic actuator(ram), (b) load cell, (c) hydraulic power supply (pump), (d) servo valve, (e) controller, (f) function generator, (g) accumulator, and (h) hoses ,wires and connections (see Fig 5.1).

The closed loop system works as follows:

(1) The controller reads the load applied to the specimen from the load cell.

(2) It then compares the signal from the load cell to that of the function generator, which has been programmed to simulate a particular loading pattern.

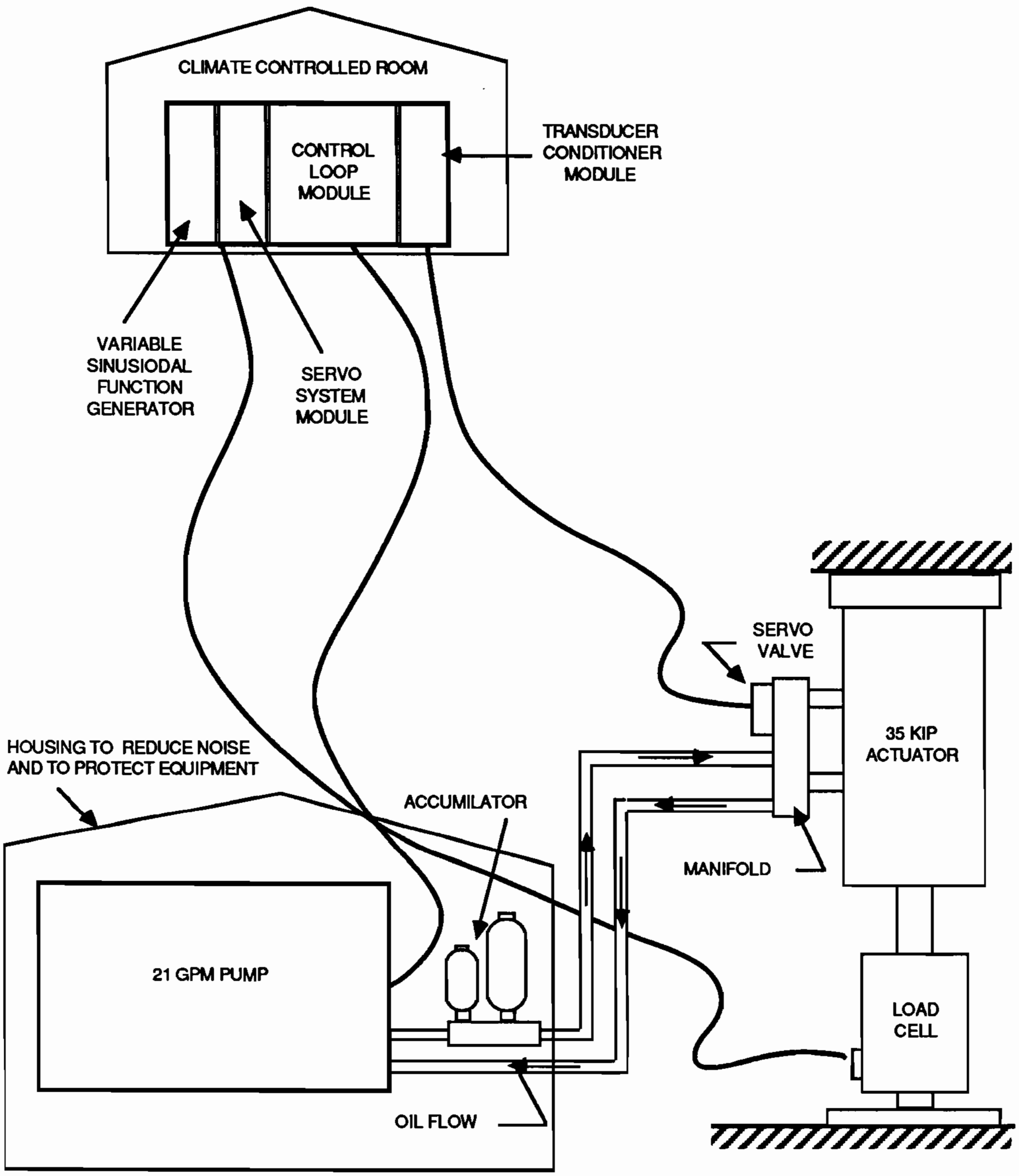


Fig 5.1. Operating schematic of the hydraulic loading system.

(3) A signal is then sent from the controller to the servo valve, which in turn adjusts the constantly circulating oil flow to the compression side or the tension side of the actuator cylinder in order to achieve the desired load.

(4) The oil flows through an accumulator going to and returning from the actuator, preventing sudden surges caused by a failure in the pumping system or the monitoring equipment from damaging the pump, servo valve, or the actuator.

Closed loop refers to constant measuring and adjusting technique which is performed be the controller, function generator, servo valve, and load cell. The system will shut down if there is any interruption of the loop, and the system will not operate unless the entire loop is complete.

Available In-House Hydraulic Equipment

Equipment described in this section was to be used for the project based on the original time schedule. These components were to be used because of their availability at that time. Keeping the equipment cost of the facility low as possible was a priority, so the proposed in-house equipment may not be the best choice. And as mentioned earlier it would eventually have to be replaced.

A Pegasus Servo Controller System (Par #510008, Serial #4976, Proj. #45005) with a built in function generator was available. Pegasus, Inc. has indicated that it would be compatible with the other desired equipment.

The 35 kip MTS actuator (Model 34G-E1 Test Actuator), which was recently purchased to be used in the half scale testing of CTR Project 457, was to be shared by full-scale facility until another actuator could be purchased. This actuator would be used while the half-scale test specimens were curing. This procedure would continue until the half-scale model testing was finished. If a new actuator had not been aquired by that time, then the original actuator would be used exclusively for the full scale testing until the end of CTR Project 457. The use of this actuator for this facility in the future is questionable because other projects have started to schedule the use of it.

<u>Hydraulic Equipment Needing to be Purchased</u>

Pegasus, Inc. and MTS, Inc. were both contacted and asked to describe equipment that would best suit the needs of the project. (Refs 3 and 7) The following list is the proposed equipment to be purchased from MTS:

(1) Model 510.21B 21 gpm 3000 psi hydraulic power supply (pump),
(2) Model 661.23x-03 22–kip load cell,
(3) Model 34G-E1 35 kip actuator, and
(4) Series 252 servo valve.

Other required miscellaneous equipment that could be purchased locally are high pressure hoses, insulated cabling, and connections for the cables.

INSTRUMENTATION AND DATA ACQUISITION EQUIPMENT

To date, the only instrumentation planned for the facility was the measurement of maximum vertical deflections at various points on the surface of the pavement. The same method of measuring the vertical deflections as that of the half scale test program was to be used at the full scale test site. For the half scale tests, the vertical displacements were measured by suspending LVDTs above the specimen. The sinusoidal movement of the LVDT rod is magnified and displayed on a storage screen oscilloscope. This allows the maximum and minimum value of the deflection to be observed and recorded.

Reading deflections from an oscilloscope is not without problems. The resolution of the deflection curve is not good for the small deflections encountered in these tests. Also, calibration of the screen has been questioned several times during the half-scale tests.

At this time, there is not an oscilloscope available, and one would have to be purchased if this method was to be used. It may be more advantageous to purchase a more general data acquisition system that can be used to read peak, minimum, and average values. It could also be used to read strain gauges and various other electronic measuring devices.

Mountings for the LVDTs will have to be fabricated. Effects of temperature changes and humidity will have to be taken into account to get accurate data. This could be difficult since beams supporting the LVDTs will span over such large specimens.

OPERATIONAL REQUIREMENTS FOR THE EQUIPMENT

Several items mentioned in this chapter require special housing to protect them from the environment, or special power requirements that may not be presently available.

Hydraulic Power Supply

A 21 gpm hydraulic power supply (pump) requires a 3-phase current at 460 volt and 60 Hz electrical source. The system requires 380 inrush amps for starting and 60 amps during continuous operation. The power supply at the proposed test site may be able to handle this electrical load by itself, but the current power supply also has to supply an air conditioner to keep the data acquisition and hydraulic controlling equipment cool as well as power this equipment. With all this extra load and the uncertain future growth of the test site, the pump will probably require its own power supply.

This high volume pump also requires a constant water supply to cool the hydraulic fluid. The system requires a constant water flow of at least 8 gpm. Presently, there is no water source at the site. Balcones Physical Plant can build a water supply and drainage system for about $1,500.00. (Ref 9) It is also suggested that an underground water storage tank be constructed so that new water does not always have to be used. Water would be circulated in a closed loop flowing from the tank to the pump and back to the tank. The ambient temperature of the soil should be able to cool the water, but this will need to be verified. The tank would only have to be routinely filled due to evaporation or maintenance. Operation of the pump would have a reduced cost and, it would not be affected by temporary loss of water supply or variance in the water pressure. This water tank would, however, require an additional small electric pump to circulate the water.

The proposed location of the pump adjoins the south side of the existing equipment building. This location should allow the use of the hydraulic equipment anywhere on the the existing fill site and on the proposed fill site. It is also near the existing power supply.

Controller and Data Acquisition Systems

The electrical equipment has to be kept in a dry climate controlled environment. The existing equipment shed would be the logical place to store and operate the equipment, but this shed may be too far from the test site. The distance criteria is based on the added resistance generated by increasing the length of wires verses the required accuracy of the tests. This is especially critical at the low end of the cyclic loading. For fatigue testing, generally, the greatest the difference between minimum load and the maximum load is desired.

Exposed Hydraulic Equipment

The actuator and load cell will be outside for months at a time subjected to the environment. This equipment has been operated outside for short periods of time, but little investigation has been made on the performance of this equipment subjected to extended exposure. The equipment may require some special protection to wind, dust, and humidity. Some sort of removable housing may be required which would be an added cost to the project.

Wires and Hoses

The wires and hydraulic hoses may have to be insulated to prevent damaging effects from temperature, moisture, and vehicle traffic. One option is to put the wires in half-buried pvc pipe.

CHAPTER 6. LOAD FRAME

The load frame suspends the actuator above the test specimen and transfers the reaction load to the foundation. It consists of a horizontal beam which spans the width of the specimen and is supported by a column on each side. The beam is designed so that the actuator can be placed anywhere along its length. This allows the load to be applied anywhere along the width of specimen of a given line. The base of the columns are anchored to lipped channels which run parallel to the length on the specimen. This allows the entire frame to be moved along the length of the test slab, thus permitting the actuator to be placed any where over the specimen within the boundaries of the load area.

DESIGN REQUIREMENTS

The design criteria of this frame went beyond just load criteria. There were several operational requirements restricting the stiffness, size, and configuration of the frame. Some of these requirements have yet to be fully investigated. To date, the following criteria have been defined.

(1) All members are sized to support the maximum static design load.

(2) The frame has to maintain minimum stiffness requirements which are restricted by the maximum allowable stroke of the actuator.

(3) The natural frequency of the frame must not be within the range the cyclic load frequencies.

(4) Fatigue has to be a primary design requirement, especially at welded connections.

(5) To reduce the chances of fatigue failure, weather protection of the frame to prevent rusting and pitting has to be provided.

(6) The maximum specimen width is 12 feet.

(7) Ease of movement of the frame is important since it may have to be moved several times during testing in order to reposition the actuator.

Design Loads

The the load frame must be able to support a static load of at least 30 kips concentrated upward and applied at any point along the length of the bottom flange. It is assumed that the maximum static load could be applied with a one inch out of plane eccentricity. The maximum allowable cyclic load for the specified deflection criteria (determined from actuator operational limits) is an upward 20-kip load, which can also be applied anywhere along the length of the bottom flange of the horizontal beam with as much as a one inch eccentricity. Any members supporting the out of plane stability of the frame should be designed to support a lateral load of at least 5 percent of maximum in plane load.

At this time, no design downward loads or minimum requirements of multiple load points have been determined. These requirements need to be estimated based on future use of the frame.

Stiffness Requirements

To accelerate the cyclic process of these pavements the number of cycles per second is increased as much as practical. With this equipment, the equivalent fatigue behavior of 20 years or more can be accelerated to as little as one week. The desired maximum loading rate for the facility is five cycles per second with a varying sinusoidal load of 200 lb to 20,000 lb. For the hydraulic equipment to work this fast, the movement of the piston of the actuator must be very small (less than 0.20 inch). This is larger than the expected deflections of the pavement (about 0.04 inch), which allows only a 0.16–inch deflection for the rest of the system including the elastic deflection of the truss, axial deformation of the columns, uplift from the foundation, and any slip of the connections. The uplift of the foundation is assumed to be negligible (less than 0.01 inch) due to post-tensioned piers (discussed in Chapter 6) The allowable slip is assumed to be 0.05 inch , which leaves 0.10–inch as total allowable movement of the frame.

It should be mentioned that the maximum stroke of the piston of the actuator is not limited to 0.20 inch. This requirement is only for 20 kips loaded at five cycles per second. Longer strokes at smaller loads or fewer cycles can be obtained. For instance, if the stroke is greater than 0.20 inch and the maximum desired load is still 20 kips, the frequency of loading would have to be reduced to about two to three cycles per second.

Dynamic Response

In order to save weight to make the frame easier to move, columns are long and narrow which might make the first several natural frequencies of the system within the range of desired cyclic loading frequencies. This would create resonant vibrations causing the loads and the deflections exerted on the frame to greatly exceed the allowables. Natural frequencies of the frame between 0.5 and 10 cycles per second should be avoided. Program SAP4 (Ref 2) can be used to determine the first several mode shapes and frequencies of the frame. The stiffness of the frame will have to be changed if there is a resonance problem. As an example, to reduce out of plane vibration of the load frame used in the half scale model tests the tops of the columns had to be stiffened by cables strung from the top of the columns to the foundation.

Welded Connections

Welded connections subjected to cycles loading are prone to fracture failures, which are sudden and could cause catastrophic damage to the facility. The chances of a fracture is increased because the frame is exposed to the environment, subjecting it to rusting and pitting. Pitting on the weld causes stress which can accelerate a fracture failure.

The chances of fracture can be greatly reduced by increasing the weld size to reduce the average stress along the weld. Longer weld lengths are preferable to thicker welds because thicker welds cause nonlinear stress distributions. Welding patterns which prevent eccentricities and stress concentrations at the ends or at the corners of the welds should be used should be used, especially when welding unsymmetric sections such as angles. The quality of the welds have to be strictly enforced. Each weld should be cleaned and primed and painted to reduce the chances of corrosion.

Span

The centers of the columns supporting the beam are assumed to be 18 feet apart. This allows almost a three foot clearance between the sides of a 12 foot wide test slab and the column.

Mobility

When casting a test specimen or changing the load position along the length of the specimen the frame has to be moved. Ferguson Laboratory has a large forklift which could be used on short notice. In the proposed design, it was assumed that the frame would have to be moved or dismantled with the assistance of only this one forklift and three to four workers.

PROPOSED CONFIGURATION

The proposed design is a portal frame consisting of two 4 foot deep horizontal trusses and two 4-inch O.D. pipes as columns. (see Figs 6.1, 6.2, and 6.3) The two trusses, which are mirror images of one another, are bolted to four special locking mechanisms which allow the height of the trusses to be adjustable. The actuator clamps to the underside of the twin trusses, and can be secured anywhere along its length. The total weight of the trusses, columns and clamps is approximately 3,355 lb Each truss weighs 1,118 lb.

Trusses

Each truss consists of two parallel 20 foot W12 x 22 beams centered four feet apart. These beams are connected by nine l2 x 2 x 3/8 angles. The angles are welded to 3/8 inch gusset plates which are welded to the flanges of the W12 x 22 beams. The gusset plates are centered on the beam flange so that the clear loads are transferred directly to the web. Spacing of the angles are such that the unsupported span of the bottom flange (bottom beam of the truss) is 3 feet, and the upper flange has a 6 foot unsupported length. All members are designed using 36 ksi steel.

Columns and Beam to Column Connections

The columns are 4 inch O.D. tubes with 1/2 inch wall thickness and are at least 11 feet long. Pin holes (29/32-inch diameter) are spaced 3 inches apart along the length of the tube. Cotter pins (7/8-inch diameter) are fitted through collars which hold the truss in place. These pin holes as well as the pins have very fine tolerances so as to give the least possible slip.

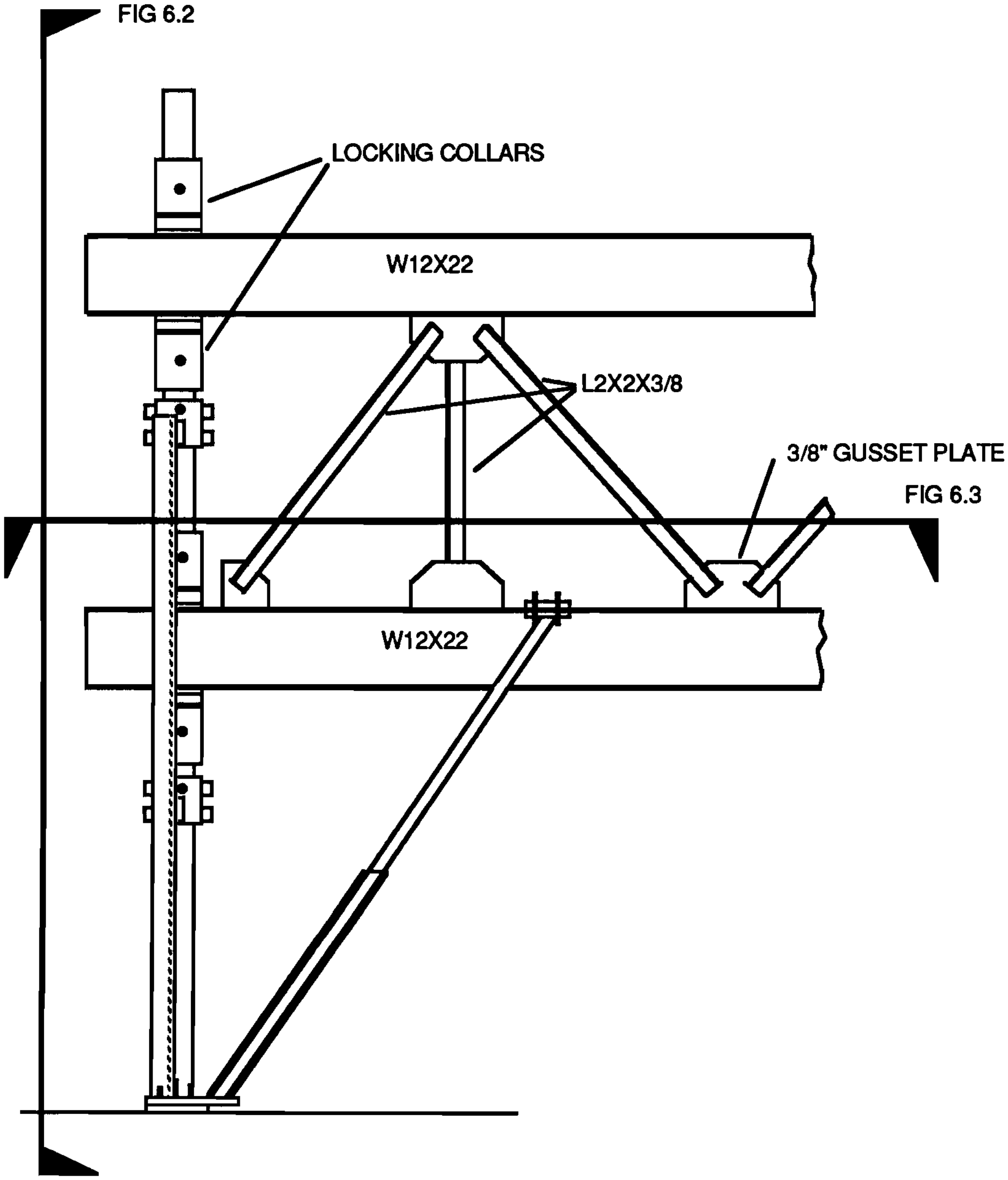


Fig 6.1. Partial elevation of load frame.

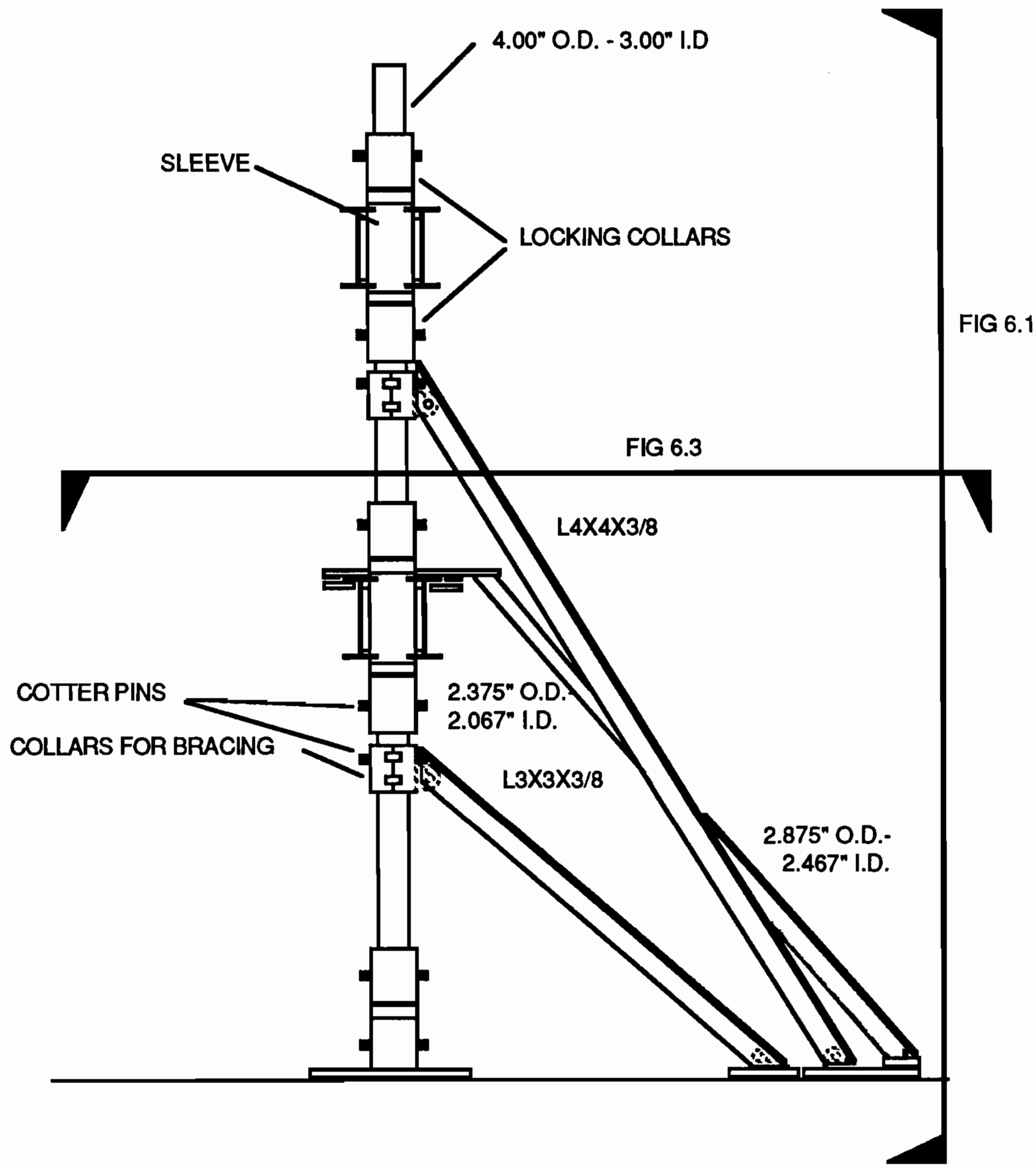


Fig 6.2. Section of load frame showing out of plane bracing.

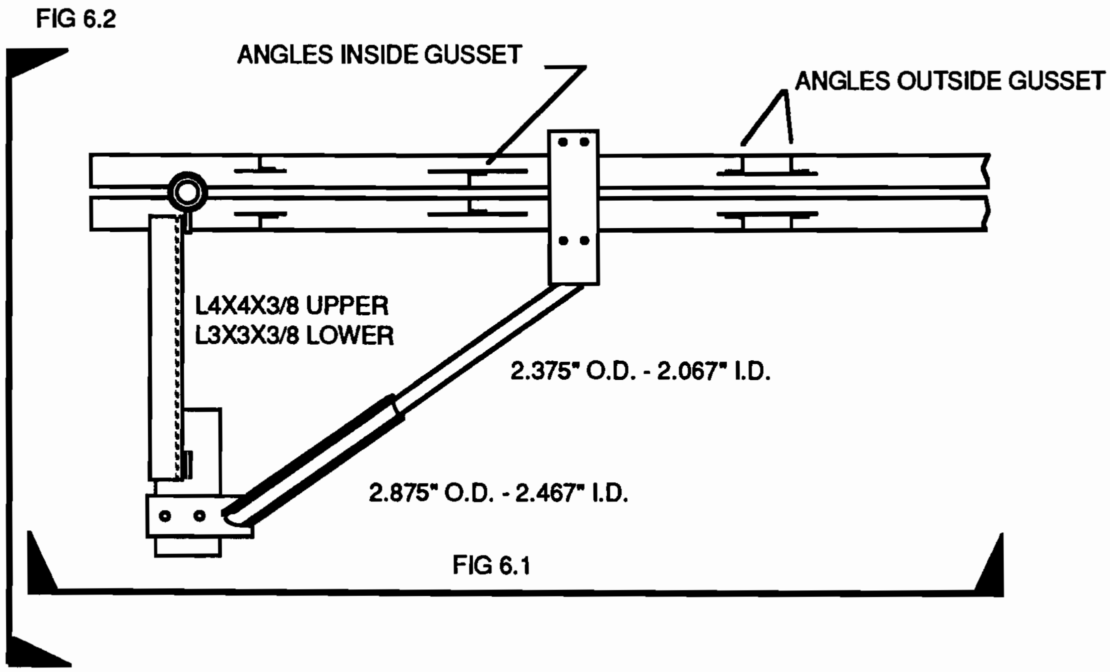


Fig 6.3. Plan of the lower flange bracing.

The trusses are connected to the columns at four points, one at each end of the truss beams. The ends of the beams are bolted to a sleeve which fits around the pipe column. Each sleeve is located between a pair of locking collars. Each collar is two pieces which screw together. One section is held to the column by a cotter pin. The free ends of each pair of collars are screwed against the sleeve between them with a spanner wrench. This locking action holds the truss in place and removes any slip from between the sleeve and collars as well as the collar and cotter pins.

The columns and clamping system are identical to that used for the load frames in the ECJ basement. Specifications for the machining of the columns, pins, collars, and sleeves are given by Wight Engineering Company(Ref 12).

This collar-cotter pin locking device was chosen primarily because of expediency and it has worked well for other load frames. Other systems would be worth investigating because this system is rather expensive. This clamping system is labor intensive and requires special equipment to fabricate. A more economical solution could probably be found.

Column Anchorage

Anchorage of the columns to the foundation has yet to be fully investigated. Originally, the same system as used for the half scale test frame was to be used. It consisted of a pipe welded to a plate which is bolted to a channel embedded in to the foundation. The end of the columns are place in the pipe and locked in place by cotter pines. This system needs to be modified to eliminate the slip from the connection during cyclic loading.

Out of Plane Bracing

Bracing perpendicular to the plane of the frame has three purposes: (a) provide lateral support to the column, (b) stiffen the columns to reduce resonance problems, and (c) reduce the length of the unsupported compression flange of the truss.

Each column is braced at midspan and at the top. The lower braces are l3 x 3 x 3/8 angles and the upper braces are l4 x 4 x 3/8 angles. All are bolted to collars which attach to the column with cotter pins. The end of the angles are bolted to plates which are anchored to channels embedded in the frame foundation (see Chapter 6). Details for the bracing connections still need to be created to reduce slip at the connections.

The compression flange bracing for the truss consists of tubular sections attached to the lower beam of the trusses approximately at the quarter points. Each brace has two tube members, 2.375-inch O.D.-2.067-inch I.D. and 2.875-inch O.D.- 2.467-inch I.D. The lower tube slides over the upper tube and allows the length of the brace to be adjusted. Adjustable braces are required since the height of the truss above the ground can vary. The upper end is welded to a plate which clamps the bottom flanges of the trusses. The other end is attached to the foundation in a similar manner as the column bracing. Once the brace is in place the tubes are bolted together.

ANALYSIS PERFORMED

To date, the frame has only been analyzed for static loading. The dynamic behavior still has to be investigated. The truss members and frame behavior are analyzed by a space frame program SAP4 (Ref 2). This program was chosen because the same model used for the static analysis can be used for the dynamic analysis. Each column was assumed to support the full uplift load applied by the actuator in tension and compression. Out of plane bracing member were sized to resist 5 percent of the maximum in plane load that occurs at their point of connection to the frame.

The design criteria for the frame were: (1) a 30-kip upward load applied anywhere along the center 12 feet of the bottom beam of the truss, (2) a 0.10–inch maximum allowable vertical deflection at midspan and 0.05–inch maximum allowable vertical deflection at 4 feet from either column, and (3) all members must comply with AISC design specification.

Space Frame Analysis

The frame was modeled as a three dimensional space frame to observe its out of plane behavior; also, the same model could be used in SAP4 to determine the primary natural frequencies and mode shapes for the dynamic analysis. Each truss was modeled individually and the out of plane bracing were also input. The computer model description and output is shown in Ref 13..

The frame was analyzed using five load cases. Each case subjected the truss to a 30–kip concentrated load at some point along the length of the lower beam. To model the maximum allowable out of plane misallignment of the actuator to the frame the 30-kip load was applied with a 1–inch eccentricity. Points of loading were located 3 feet, 4.5 feet, 6 feet, 7.5 feet, and 9 feet from the left column. [see Fig 6.4(a)] Loads were not applied to the right side of the frame because of symmetry. Right side members were sized according to the maximum loads resisted by the corresponding members on the left side. The maximum load that each member was subjected is also shown in Fig 6.4(a).

Truss members in the proposed configuration were sized to meet the deflection criteria. All the angles were sized the same for ease of construction; this was also true for the truss beams. The deflection envelope of the lower beam of the truss for the moving 30-kip load is shown in Fig 6.4(b).

Columns

The 4–inch O.D. x 1/2–inch pipes were chosen because of the clamping system used to keep the truss in place. These columns far exceeded the load requirement of resisting a 30–kip load. The maximum tensile load for the column was 115 kips and the maximum compressive load was 96 kips.

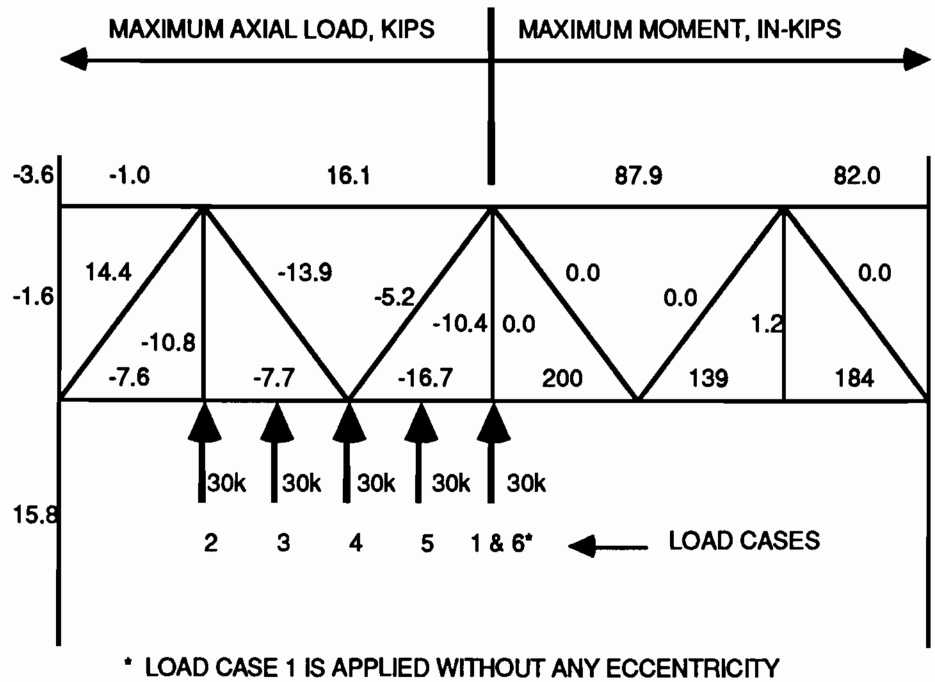
Bracing

The lower bracing for the columns was sized to support 5 percent of the maximum tensile load (30 kips) in compression. The upper column bracing is sized for half that load.

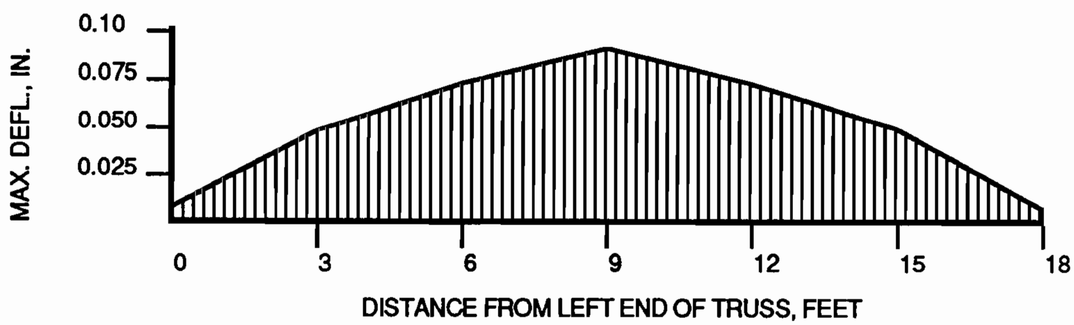
Maximum axial load for the lower beam of the truss was 25 kips (sum of loads in both lower beams). The members providing lateral bracing for the compression flange of the truss were designed to support 3 kips axial compression. The effective length of the brace was assumed to be 8.5 feet.

ALTERNATIVE DESIGN

An alternative design for the load frame is discussed in this section. This configuration uses a single wide flange beam to span between the columns. The columns and the column bracing remain the same.



(a) Maximum axial forces and moments induced by the applied loads.



(b) Maximum deflection envelope for the applied load cases.

Fig 6.4. Member forces and deflection envelope of proposed load frame.

The beam is sized from the same deflection criteria as the truss (0.05–inch maximum deflection with the load applied 4 feet from the end and 0.10–inch maximum deflection with the load applied at midspan.) Figure 6.5 shows the beam and its column connection. The beam is a W24 x 84 and 16 feet, 2 inch long. Vertical stiffeners are placed on both sides of the web at 36 inch spacing. Beam ends are bolted to a sleeve which is held in place by locking collars similar to the ones described in the previous design.

The beam is lighter than the truss and is easier to construct. For loads of less than 38 kips, no lateral support along the length of the beam is required. A summary of the maximum allowable loads under various restraints ise shown in Table 6.1.

The sleeves and the collars are designed to support at least 100 kips.

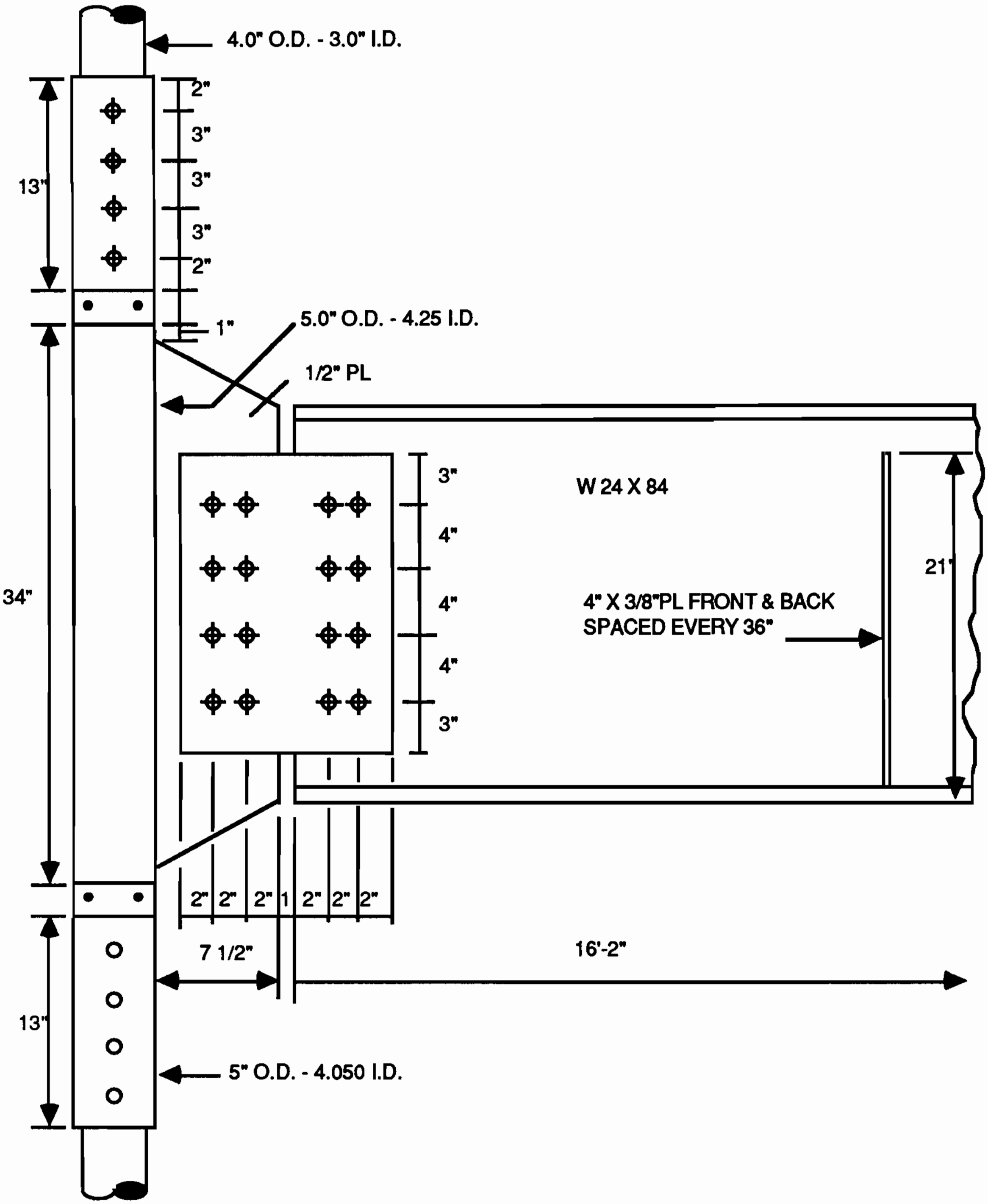


Fig 6.5. Single girder alternate solution.

TABLE 6.1. MAXIMUM ALLOWABLE LOADS FOR W24 X 84 BEAM

Load 4 feet From End	Load at Midspan	
0.044 inch	0.092 inch	Deflection w/30 k load.
		Maximum Load with 1" Eccentricity.
53k	38 k	Unsupported Length = 18 ft
66k	47.5 k	Unsupported Length = 12 ft
		Maximum Load with No Eccentricity.
86k* 76k	60k	Unsupported Length = 18 ft
115k* 76k	80k* 76k	Unsupported Length = 12 ft

*Load has to be centered under bearing stiffner; otherwise use maximum load of 76 kips.

CHAPTER 7. ANCHORAGE OF THE LOAD FRAME

This facility is designed to apply a downward load to a slab on roadbed. This creates an uplift force on the load frame which must be resisted by an anchorage system. As discussed in Chapter 6, this anchorage has to act as a point of fixed translation for the base of the load frame. The anchorage system must also allow the load frame to be placed anywhere along the length of the test slab.

DESIGN REQUIREMENTS

The primary requirement of the anchorage is to prevent the vertical movement of the load frame, especially during cyclic loading. Vertical slip of the anchorage system during cyclic loading is assumed be negligible (less than 0.02 inch) due to operational limitations of the hydraulic equipment. The design loads are based on the conservative assumption that the maximum design load of the frame can be supported by one column; so, the anchorage of each column must resist a minimum static load of 30 kips with no maximum vertical slip requirements and a maximum cyclic load of 20 kips with the vertical uplift being less than 0.02 inch .

SOIL CONDITIONS

The existing site consists of a one to two foot layer of stiff soil on top of a limestone base. When the roadbed is built, it is assumed that the stiff soil will be replaced by soft clay 3 to 5–feet deep.

CONCEPTUAL DESIGN

The design of the anchorage system is complicated due to the deflection criteria. Until a survey of the soil properties of the proposed site and of the proposed clay the fill mound has been made, it is impossible to design of the anchorage. Two conceptual designs are discussed in this chapter, but a final design will require the assistance of a geotechnical engineer.

The anchorage of the load frame is divided into two primary components; two parallel slot beams eighteen feet apart and the anchors. The footing of the load frame are bolted to the slotted beam. The anchors provide the fixity to hold the beams in place.

Slot Beams

The slot beams are assumed to be at least 12 feet long and about 3 feet wide. The upper surface of these reinforced concrete beams has an imbedded channel with lips as shown in Figs 7.1 and 7.2. These channels are detailed the same way as the channels imbedded in the floor of the ECJ basement. (see Ref 13 for details) The load frame is bolted to these channels. This type of attachment of the load frame to the beam allows the frame to be attached to any point along the length of the beam.

Anchorage of the slot beams would normally be provided by using piers drilled into bedrock, but due to the very strict deflection criteria for cyclic loading, normal drilled piers would not work. To resist uplift load, shear friction must be generated by some movement of the pier wedging the side of the pier against the limestone. This vertical movement required to generate the shear resistance can be greater than 0.20 inch and it can progressively grow under cyclic loading.

Dead Weight Anchors

The easiest method of anchoring the beams is to make the beams large enough so that the dead weight of the slot beams is greater than the maximum design uplift load. This method would resist the uplift loads without having to generate any shear resistance with the soil. If, the blocks were designed to resist the low dynamic loads that the frame would experience in CTR Project 457, it would limit the site to relatively low static and dynamic loads for future projects. For example, if each beam was 3 feet x 4 feet x 12 feet, the maximum operating load of the facility would only be 20 kips.

Depending on the composition of the proposed fill mound material, there may be settlement problems of this type of foundation. Uneven settlement or lateral movement could cause gaps between the anchor and soil which may promote lateral shifting or rocking during cyclic loading. This would not be acceptable.

Post-Tensioned Piers

A more promising method of anchorage is to use post-tensioned piers attached to the under side of concrete beams by cables or rods as shown in Figs 7.1 and 7.2. Each beam would be anchored by three (or more, depending on the final beam length) evenly spaced piers. The piers would probably be drilled about 6 feet into the bedrock, so the total pier depth would be about 10 to 14 feet. Post-tensioning is used to develop full shear resistance against the rock prior to testing so that the only uplift of the foundation during testing would be from elastic deformation of the pier. Figure 7.3 shows the load distribution of a beam anchored to a post-tensioned pier. Only elastic deformation of the system would have to be taken into account when calculating the maximum stroke of the actuator. The maximum uplift capacity of each beam allowing movement to generate additional shear resistance would probably be greater than 80 kips. The post-tensioning system could be designed so that the tensioned bars could be later retightened to correct any long term stretching of the bars or slip of the piers which may occur.

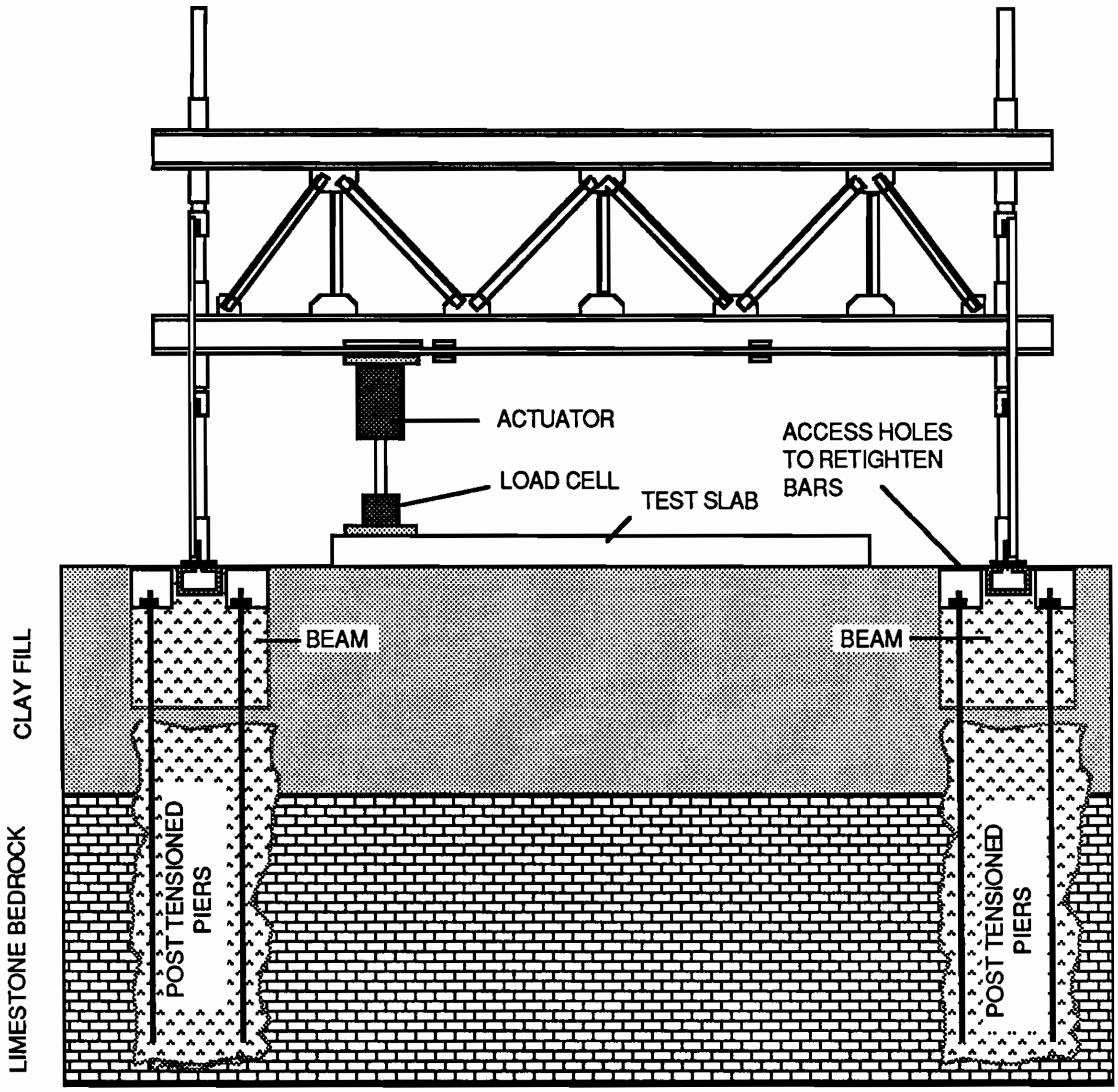


Fig 7.1. Elevation of the proposed load frame and anchorage system.

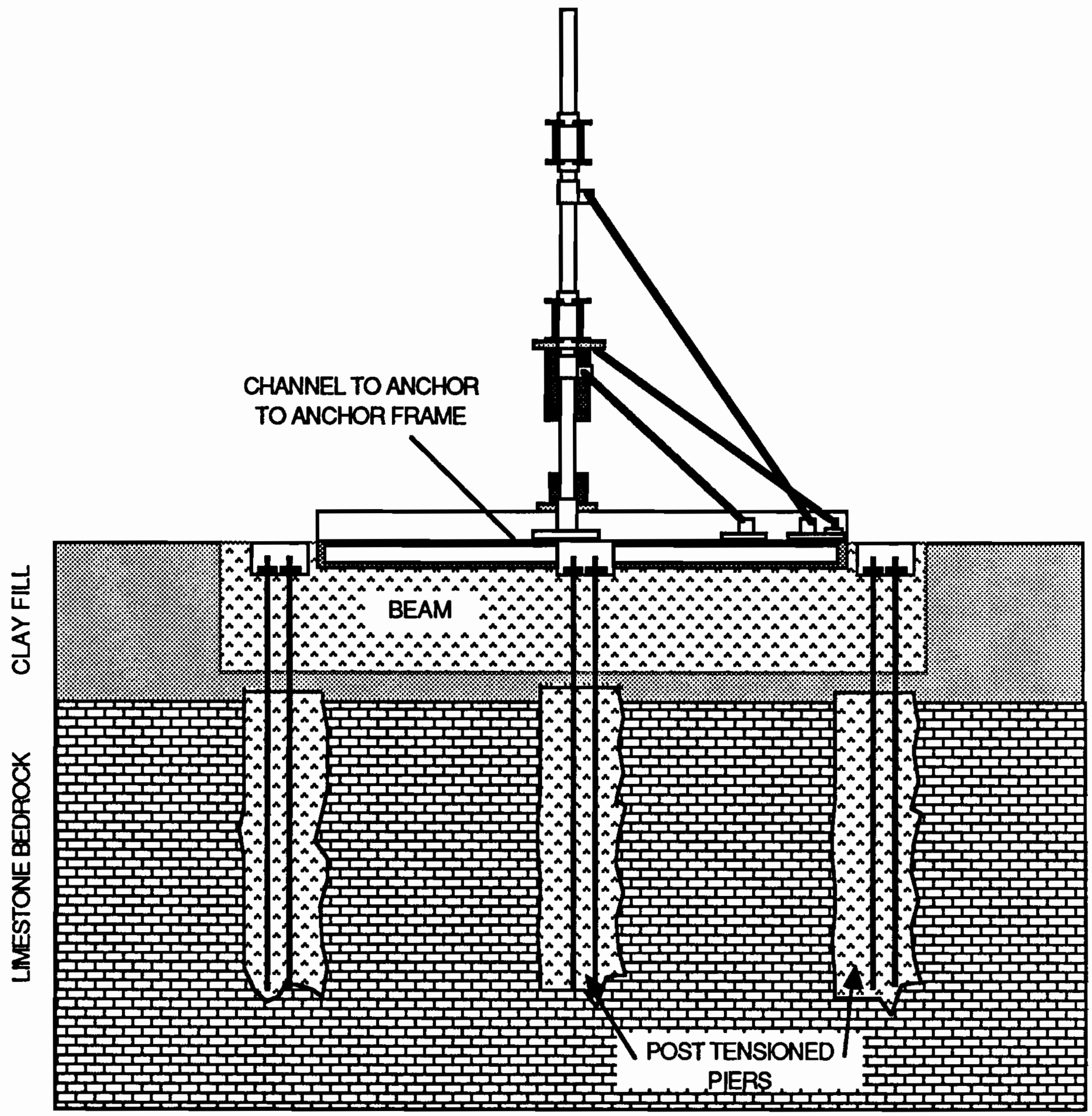


Fig 7.2. Profile of proposed load frame and anchorage system.

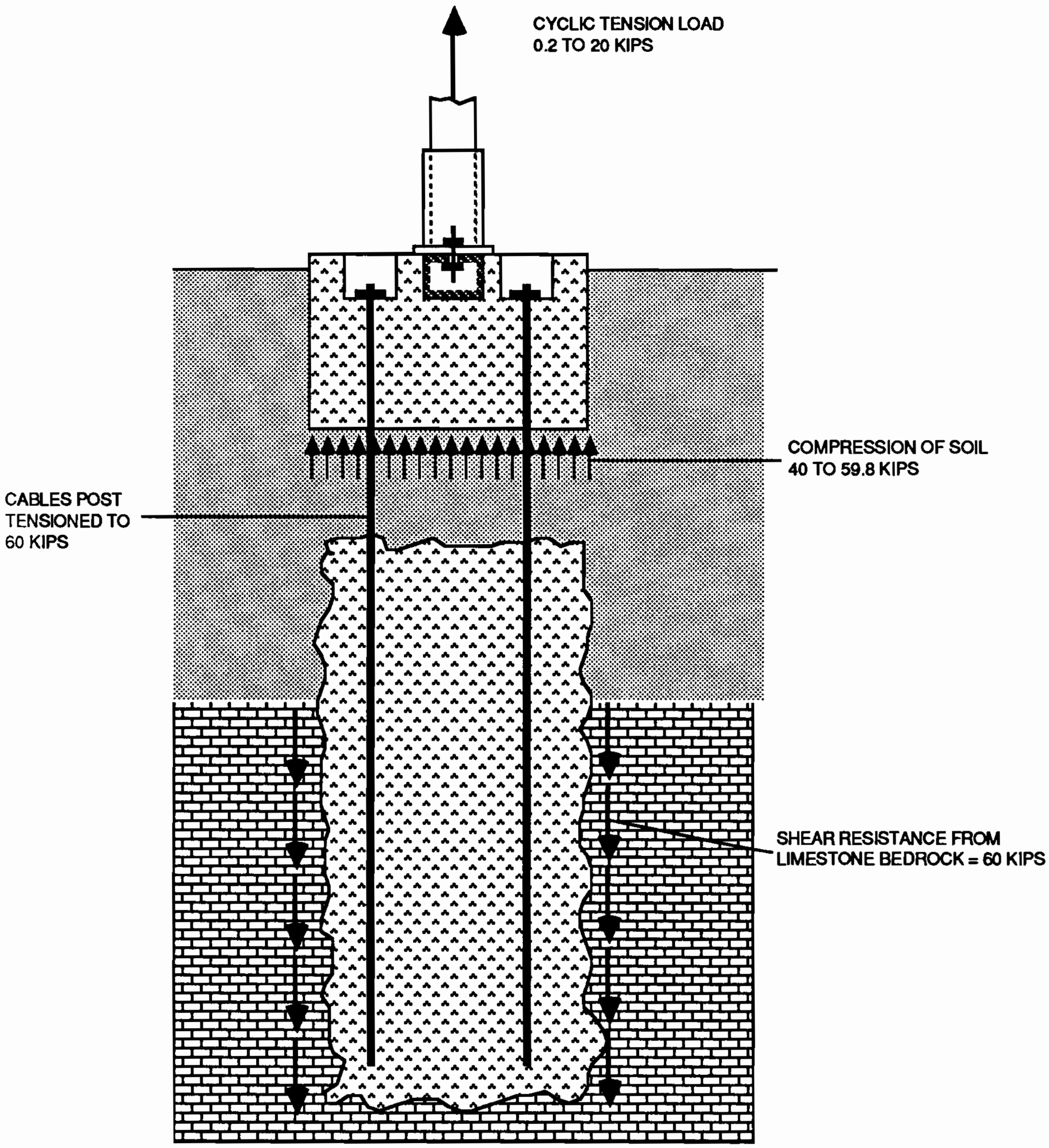


Fig 7.3. Load distribution of an anchorage mechanism of typical load of 0.20 to 20 kips with post–tensioning of 60 kips.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

Designing and building this test facility is much more complicated than first envisioned, but the project should be feasible providing that an adequate roadbed can be created.

CONCLUSIONS

The proposed facility should have the following operating criteria:

(1) The maximum specimen size is 24 feet long and 12 feet wide.

(2) Loads are to be applied by a single hydraulic actuator suspended over the specimen by a portal frame anchored to the foundation by post-tensioned piers.

(3) The actuator can be placed anywhere within the center 12–foot x 12–foot area over the specimen.

(4) Maximum static load is 30 kips and the maximum cyclic load is 20 kips at a rate of at least 3 cps.

(5) The roadbed will be a fill mound such that dynaflect readings from specimens, described in Chapter 2 and supported by this roadbed, would produce similar dynaflect results as that of sections of the 610 Loop in Houston, Texas in same state of distress.

(6) The facility could be used continually year round.

(7) The facility would be accessible to heavy equipment such as forklifts to move the specimens and concrete trucks to place specimens.

A preliminary estimate of the cost to construct this facility is about $60,000. (Ref 14) The costs for the major components discussed in this paper are listed in Table 7.1. This is a minimum cost of the facility. Depending on foundation requirements and the hydraulic equipment that will eventually have to be bought, cost could approach $80,000 to $100,000.

The most important conclusion that should be learned form this study is that the design and construction of this facility is a multi-disciplinary effort. The design requires expertise from the transportation, structural, geotechnical, and mechanical engineering disciplines. Transportation and structural engineers can determine what performance criteria are required of the facility. The geotechnical, mechanical and structural engineers are required to determine the feasibility and needed hardware to construct the facility.

At this time, the design of the facility is governed by creating a loading system and its supporting structure that can apply continuous cyclic loads at three to five cycles per second, and by designing a roadbed system that adequately simulates continuous highway pavement roadbed. Both of these problems require a detailed knowledge of the soil structure of the proposed test site and a detailed analysis of the load paths of the action and reaction of applied loads to the specimen.

RECOMMENDATIONS

Design of this project should be joint project performed by structural and geotechnical engineers and supervised by the Center for Transportation Research. The hydraulic requirements are pretty well defined at this time and future mechanical expertise can be contracted from MTS or the University Physical Plant. The Center for Transportation Research should define the operating specifications and be arbitrator when there is conflict between the cost of construction and compromising the performance of the facility. The actual design and coordination of construction will be the responsibility of the structural and geotechnical engineers.

TABLE 8.1. COST ESTIMATE OF THE PROPOSED TEST FACILITY

Roadbed Construction	$ 7,900.
Hydraulic and Electrical Equipment	26,300.
Load Frame Fabrication	8,500.
Load Frame Anchorage	13,800.
Total	$ 59,000.

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