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DEVELOPMENT OF AN ACCELERATED TESTING LABORATORY FOR HIGHWAY RESEARCH IN KANSAS

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16. Abstract

This report discusses the development of the Kansas Accelerated Testing Laboratory (K-ATL) at Kansas State University (KSU). An advisory committee was formed including transportation experts from Colorado, Iowa, Missouri, Nebraska, Oklahoma, and the Federal Highway Administration to aid development.

A tandem axle assembly moving at 8 km/h (5 mph), or a pulse load system with hydraulic actuators, can apply up to 178 kN (40,000 lbs.) on flexible or rigid pavement specimens 6.1 m (20 ft.) long and up to 6.1 m (20 ft.) wide. Environmental and temperature control features allow a section of pavement to be heated or cooled either from the top or bottom in an insulated 3.7 m x 6.1 m (12 ft. x 20 ft.) environmental pit. Temperature ranges between -23°C and +66°C (-10°F and +150°F) are possible. Water level is controlled through a sprinkler/drainage system in the test pits that are 1.8 m (6 ft.) deep.

Between January 1997 and August 1997, two experiments were conducted at the K-ATL. The first experiment consisted of 76 mm (3 in.) of asphalt overlay over a 102 mm (4 in.) cold in-place recycled (CIPR) base stabilized with fly ash. This test resulted in the application of 168,000 load repetitions using the wheel carriage (tandem axle with dual wheels loaded to 151 kN (34,000 lbs.)) and tire pressure of 620 kPa (90 psi.). The second experiment was the testing of Portland Cement Concrete Pavement (PCCP) load transfer devices. Using the same subgrade and aggregate base, three sections of 229mm (9in.) pavement were placed in the same pit. The pulse loading assembly (thumper) was used to apply a cyclic load to the PCCP joints and a total of 7.4 million load repetitions were applied during the testing. These two experiments were most useful to identify the kinds of problems that can arise during the different types of testing and to ascertain the actual physical capabilities and limitations of the test equipment.

The facility was constructed to suit the needs of the surrounding state agencies and industries. A regional pooled fund study to conduct ongoing accelerated testing was created by the FHWA Region 7 states.

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Accelerated, pavement, testing joint, load transfer, environmental, distress, rutting, pooled fund, pulse loading, tandem axle.

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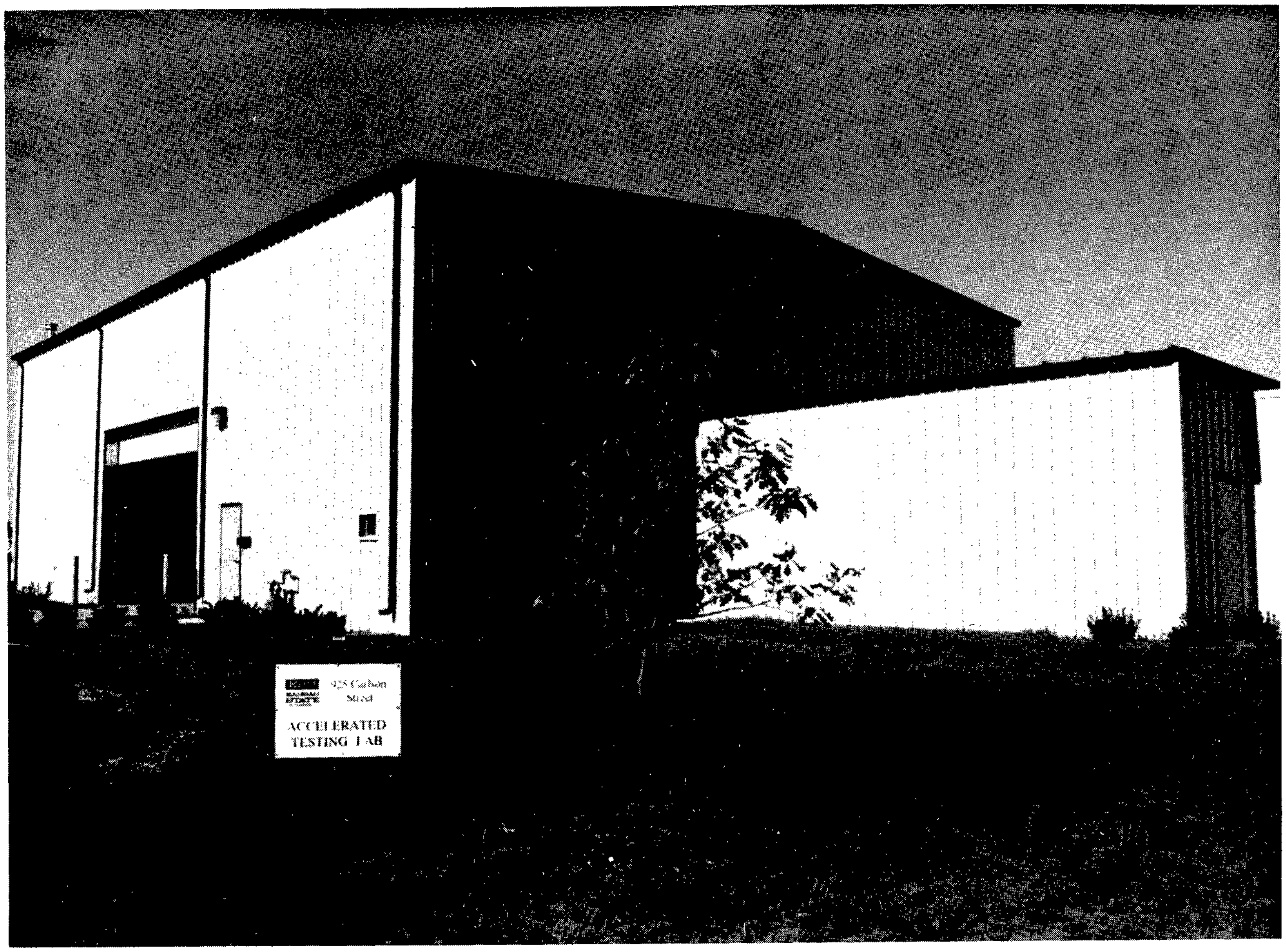

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ABSTRACT

Accelerated testing of pavement in ambient and various temperature/moisture conditions is highly desirable to prove, in a timely manner, innovative concepts in design and demonstrate the performance of new materials and mixes presently under investigation or expected in the near future. For this reason, the Department of Civil Engineering at Kansas State University (KSU) and the Kansas Department of Transportation (KDOT) have completed the development of the new Kansas Accelerated Testing Laboratory (K-ATL) at KSU. The development project is supported by an industrial partner, Cardwell International, Ltd. of El Dorado, Kansas, who performed the design and construction of the testing machine. A matching grant has been awarded by the Kansas Technology Enterprise Corporation (KTEC) to support the project and subsidize the construction, development, and operating costs. Private donations from KSU alumni have allowed the College of Engineering to construct the new building.

A tandem axle assembly moving at 8 km/h (5 mph), or a pulse load system with hydraulic actuators, can apply up to 178 kN (40,000 lbs) on flexible or rigid pavement specimens 6.1 m (20 ft) long and up to 6.1 m (20 ft) wide. Environmental and temperature control features allow a section of pavement to be heated or cooled either from the top or from the bottom in a 3.7 m × 6.1 m (12'×20') environmental pit. Temperature ranges between −23°C and +66°C (−10°F and +150°F). Water level is controlled through a sprinkler/drainage system in the test pits that are 1.8 m (6 ft) deep and insulated with a waterproof membrane.

The research team has been working closely with KDOT personnel to determine KDOT's long-term needs and to design and schedule the required tests. The facility was constructed to also suit the needs of the surrounding state agencies and industries. For this purpose, an advisory committee has been formed including transportation experts from Colorado, Iowa, Missouri, Nebraska, Oklahoma, and the Federal Highway Administration (FHWA).

Between January 1997 and August 1997, two experiments were conducted at the K-ATL. The first experiment consisted of 76 mm (3 in.) of asphalt overlay over a 102 mm (4 in.) cold in-place recycled (CIPR) base stabilized with fly ash. This test resulted in the application of 168,000 load repetitions using the wheel carriage (tandem axle with dual wheels loaded to 151 kN (34,000 lbs) and tire pressure of 620 kPa (90 psi). The second experiment is the testing of Portland Cement Concrete Pavement (PCCP) joints. Using the same subgrade and aggregate base, three sections of a 229 mm (9 in.) pavement were placed in the same pit. The pulse loading assembly (thumper) was used to pound the different types of PCCP joints, and a total of 4.7 million load repetitions were applied during this time period. This period included many interruptions to debug the system, perform repairs and modifications to the machine, and conduct Falling Weight Deflectometer tests on the specimens. These two experiments were most useful to identify the kinds of problems that can arise during the two different types of testing, and categorize the necessary repairs and their respective efficiency and downtime. They also helped ascertain the actual physical capabilities as well as limitations of the testing equipment.

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1. BACKGROUND

Improving pavement performance in the United States is presently the subject of a major national effort. As part of this effort, the Kansas Department of Transportation (KDOT) is designing a number of new pavement mixes and structures. On the other hand, Portland Cement Concrete Pavement (PCCP) is becoming more commonly used in new constructions as well as for highway resurfacing, retrofitting, rehabilitation and reconstruction (4R). Concrete overlay -- known as white topping -- installed on the top of existing deteriorated asphalt road surface has shown many advantages over asphalt resurfacing. In both new constructions and overlays, shear transfer devices between adjacent pavement slabs currently consist of steel dowels. However, problems with PCCP have been observed at these joints and new shear transfer devices, --such as *X-FLEX* which was invented at Kansas State University (KSU)--, have been proposed to avoid such problems.

In order to learn more about the performance of these new designs and products before they are put on the road, large scale testing is necessary in an experimental setup that best simulates actual road conditions and that is most representative of real world situations. Actual road conditions include exposure to both highway traffic (repetitive loading) and adverse environmental effects (temperature and moisture variations).

For these reasons, the Department of Civil Engineering at KSU and KDOT developed the new Kansas Accelerated Testing Laboratory (K-ATL) at KSU. The development project is supported by an industrial partner, Cardwell International, Ltd. in El Dorado, Kansas, who performed the design and construction of the testing machine. A matching grant has been awarded by the Kansas Technology Enterprise Corporation (KTEC) to support the project and subsidize the construction, development, and operating costs. Private donations from KSU alumni have allowed the College of Engineering to construct the new building.

1.1 Project Objectives

The objectives of this project are to design, construct and install testing equipment to apply computer-controlled wheel loads to pavement/slab test sections under constant (normal) or variable (monitored) laboratory environmental conditions. A wheel load assembly that can apply up to 178 kN (40 kips) on the surface of the test specimen needed to be achieved. The speed of the moving load would be around 8 km/h (5 mph). In addition, specialized equipment for environmental control (heating and --especially-- cooling) of the pavement test sections was necessary to simulate the effect of adverse temperature and climate changes. A temperature range of -23°C to +66°C (-10°F to +150°F) would be the desired capabilities of such temperature-control equipment.

The K-ATL was to have 1.8 m (6 ft) deep test pits that can be used to perform experiments on the type of soil and subgrade underneath the pavement sections that are be tested, degree of compaction, effect of the water table, and other soil/subbase-related research of interest to KDOT. Other potential applications may include composite bridge decks, expansion joints of bridges, fatigue of steel or concrete highway bridges, and precast/prestressed bridge girder connections.

The K-ATL will be used to perform a variety of testing experiments for highway applications. This includes studies of the *X-FLEX* system and alternate shear transverse devices, and a variety of highway materials (asphalt, concrete, and combinations of both). Modern testing equipment will allow for advanced accelerated testing that will expose full size pavement sections to sophisticated simulated highway truck loadings (wheel loads) and environmental conditions (temperature and humidity). These tests will provide more realistic test results that will supplement other current research. For instance, the facility can be used to test SHRP mix designs and the results should be most meaningful to all highway officials who are using the Superpave design method.

For asphalt concrete pavement research, this facility can be very instrumental in testing pavements at the elevated temperatures. Although pavement temperatures as high as 80°C (160°F) have been reported, the most likely test temperature will be approximately 60°C (140°F). Different types of mixes can be tested, particularly the asphalt-rubber mixes. Thermal characteristics of asphalt pavement can also be investigated. Super singles could be used in which, for example, one wheel could run on a control slab, and the other wheel on the experimental slab.

1.2 The *X-FLEX* System

X-FLEX was the initial reason to construct an accelerated testing laboratory at KSU. After the conception of the idea and preliminary investigation, it was deemed necessary to test the system in full-size concrete pavement slabs under loading situations most representative of highway traffic conditions. *X-FLEX* is a slab, shear-transfer device invented by Dr.'s Hu, Kirmser, Swartz, and Hossain at the Department of Civil Engineering, Kansas State University. The superior performance of the device is based on its ability to transfer shear by direct stress rather than through direct shear and bending [Hu, 1995]. This is accomplished by utilizing the truss concept. It has flexible sleeves to cover the inclined members of the steel truss to provide flexibility for almost stress free expansion. It also allows for distributing the bearing stresses on concrete over a large area to develop the required tension or compression for transferring the shearing forces. This eliminates singular points which produce damaging effects including high stress concentrations at the contact points between the dowel and the edge of the concrete which cause a significant reduction in the life cycle of the joint. It also reduces tearing stresses in concrete resulting from bearing between the steel dowel and the concrete.

The preliminary testing of the *X-FLEX* system -- using the same amount of steel as for regular dowels -- has shown very important advantages. Initial analytical studies and experimental work on small size specimens confirm that its performance is 50% greater than dowels in transferring shearing forces [Hu, 1995]. Also, using 4 HZ dynamic loads ranging from 27 kN to 80 kN (6 kips to 18 kips), the number of cycles to cause fatigue failure for *X-FLEX* is 250,000 as opposed to dowels which is 1,000 cycles. Therefore its service life is much greater than that of dowels [Gan, 1994].

When using *X-FLEX*, less maintenance and rehabilitation would be needed resulting in substantial saving in repair costs, traffic interruptions, and time delays, and an improved public safety and driving comfort. The testing report summarizing the results of the preliminary study conducted at KSU is given in [Hu *et al*. 1994]. Subsequent test results on larger specimens and full size slabs are addressed later in this report (Section 4.3).

1.3 Overview of the Research Plans

The project described in this report was considered to be an initial investment by KDOT that will payoff rapidly within a few years. In addition to the initial phase, KDOT agreed to commit two years of support for the lab activity. It was expected that KDOT would continue to support the laboratory and contribute to the first few years development and operational costs. It was understood that this project would be complemented by a contribution from a private industry partner, a grant from KTEC, and resources from KSU for the building and personnel.

1.3.1 KDOT Initial Project

The initial research contract between KSU and KDOT was entitled "Development of an Accelerated Testing Laboratory for Experimental Studies to Mitigate the Deterioration of Highway Pavement in Kansas" (KDOT Project C706). The starting date for this effort was July, 1,1994. The estimated duration of this phase of the project, --originally--, was 12 months. The effort in this initial stage of the project mainly consisted of designing, constructing and installing specialized equipment for the application of monitored environmental conditions. This was to be done in coordination with other tasks such as design of lab space, wheel load equipment, etc.

It was anticipated that the testing facility would be ready for testing by June of 1995. However, tests related to the X-FLEX system were to be performed first. Therefore, actual testing for other KDOT projects in this laboratory would start following these tests.

The work in the initial phase (12-month) of this multi-year effort was expected to proceed according to the following work plan and schedule (excerpt from the first agreement executed on July 18, 1994).

"Task 1. Design of the heat exchanger and cooling/heating system

This includes studying the heat transfer properties of the cooling/heating system including the diameters of the pipes, refrigerant needs and storage capacity, heat exchanger pattern and system configuration. Several investigations are needed to optimize the system configuration with respect to needs for cooling time, frequency of temperature cycles, temperature ranges, etc. This task will require closer consultation with KDOT to determine the most probable types of experiments and tests for which the facility will be used in the future.

The formation of an advisory committee including KDOT experts and engineers will be essential to the success of this task and the subsequent tasks. This panel of experts should be established at an early stage of this phase of the project so that the equipment, instrumentation, and design configuration of the environmental control facility will have the capabilities that perfectly match KDOT needs and the requirements for the desired type of experiments (rutting, fatigue, cracking, freeze/thaw, etc.). Contacts with the Accelerated Loading Facility (ALF) experts at the U.S. FHWA and with members of the Accelerated Pavement Testing User's Group have been initiated. Further consultation and interaction with these persons will be pursued.

Task 2. Assembly and fabrication of the environmental control system

This task includes purchasing the necessary parts for the system. Different alternatives will be investigated to minimize fabrication and installation costs. The possibility of ordering some ready-to-use equipment parts will be studied as opposed to purchasing material and supplies and fabricate the parts.

The assembly and installation of the essential parts will be carried out during this task. This task will begin right after the completion of Task 1. However, depending upon the availability of space and the construction schedule of the ATL building, the system may not be completely installed until the later part of this first-year phase.

Task 3. Adapt environmental system to mechanical testing frame

The environmental system will be installed in accordance with the size, space, and performance requirements of the test pit and specimen types. For instance, provision for confining or tying down the edges of a concrete slab that would expand or contract under varying temperature will need to be considered. The system should be such that, when adjacent to the uncontrolled (normal condition) testing, it would behave as a whole unit under the same loading frame/device.

Work in this task also will include attaching different control devices, fixture, and hook-ups (hydraulic and power). Part of the effort here will overlap with the installation and hook-up of the mechanical system and loading frame apparatus.

Task 4. Calibration and prototype testing/optimization

This will consist of testing the performance of the system and apparatus to determine the optimum operating temperature range, the constraints near the upper and lower limits, and the corrective actions or alternate options to overcome errors in fabrication, construction, or design. Additional instrumentation and measuring/reading devices will be identified. The *X-FLEX* system/specimens will be used to obtain feedback on the system operation and performance with concrete pavement. Calibration will result in some standard methods/practices to achieve desired temperature in a certain time-range such as thermostat settings, valve opening, usage of insulating blankets, etc.

Task 5. Study testing requirement and schedules

This task will be initiated at the end of this phase, and will proceed into the subsequent phases (following two years). Based on preliminary experimentation with the *X-FLEX* system/specimens, more information will be available on the system performance and capabilities/limitations. In the subsequent phases the system will be calibrated to operate in its optimum performance, and therefore it will be possible to determine the duration, cost, and limitation for each type of potential application that would make use of the system. When completed, this task will result with a table that will then be used to determine the requirements for each job, the test duration, the number of tests to run per year, etc. This will be used later in conjunction with the mechanical testing load frame capabilities to generate a schedule of work and charges for the different type of tests to be run in the facility. This will also help the future activity in the lab and the number and type of jobs to accommodate for.

Task 6. Progress reports and summary of accomplishments

Quarterly progress reports describing the various development stages of the ATL in general and the temperature/moisture system in particular will be prepared and submitted to KDOT. All conclusions, preliminary experimental results, and recommendation determined while conducting this phase of the project will be presented in an end-of-the-year report. Design calculations (heat transfer, stresses/strains, deformations, deflections, etc.) will be provided in the first annual

> report. The operating speed, capabilities, and performance of the constructed system will be assessed. Proposed testing speed, frequency, and costs (charges) to the different identified and potential users will also be given.
>
> At the discretion of KDOT engineers and the advisory panel, results may be disseminated upon request in national meetings and/or technical conferences. The PI's of this project at KSU will work with KDOT officials to present the progress in the lab development and the research findings to the engineering community in a suitable form, such as journal publications and technical presentations."

As mentioned above, the estimated ending date for this effort was June 30, 1995. However, due to a variety of reasons, the work did not progress according to the planned time schedule. The main reasons for the delay are attributed to difficulties in securing private funds and donations for the construction of a new building, obtaining building permits and contracting out the construction job, and trying to implement, --as many as possible--, the recommendations made by the Advisory Committee to enhance the lab capabilities and testing options. It was therefore necessary to make amendments to the original agreement and two no-cost time extensions were executed, first to August 31, 1995, and then to January 31, 1996.

1.3.2 KDOT Project Extension

By January of 1996 it was evident that more time and money would be needed to complete the development of the facility with all the desired additional features. A substantial increase in the total budget and another year extension to KDOT Project C706 was proposed by KSU and approved by KDOT. The ending date of the project was then extended to December 17, 1996.

This increase and extension allowed: (1) the completion of the tasks described in the original work plan (as outlined in the agreement signed on July 18, 1994), and (2) the purchase, delivery, and installation of the additional heating/cooling panels and radiating heat lamps, as recommended by the project Advisory Committee. The justification for the time/cost extension was as follows (excerpts from the extension agreement executed on January 18, 1996):

> "The different enhancements recommended by the committee concerning the configurations of the test pits/floor, the loading device, and the environmental system -among other factors-- have caused modifications to the building design and consequently a general delay in the design/construction activity and increase in costs. Increasing the depth of the environmental pit from 1 ft to 6 ft, adding the adjacent pit/tunnel for the pipes/manifolds connection, increasing the number of holes/sleeves through which the pipes would pass to the pit from one row to six rows at 8 inches vertical interval, and providing tie-down bolts and anchors for the slab to restraint it from contracting when cooled and therefore better simulating a continuous pavement section, are some examples of such enhancements. Note

that all these enhancements are included in building construction costs and thus are not charged to the project."

"Also, in order to augment the cooling capabilities to freeze 6 ft of subgrade, as opposed to 1 ft, a larger-capacity and henceforth more expensive chiller and compressor were needed compared to the ones configured and priced in the original agreement. It has been possible to purchase this equipment following the budget revisions (at no additional cost) approved by KDOT on July 27, 1995. These revisions included shifting the funds in budget line-item "materials and supplies" to line-item "equipment," to make-up for part of the cost difference. However, materials and supplies are still needed to complete the installation of the thermal system."

"A major enhancement of the thermal system that was not included in the original agreement involves adding surface cooling panels and radiating lamps so that pavements could be cooled/heated from the top down. This duplicates usual natural conditions and allows the flexibility to control the temperature gradient through the pavement and subgrade. This would also allow testing cold pavement on an unfrozen subgrade conditions. It was also desirable to add a second system of piping and manifolds for the surface heat exchanger, separate from the one for the exchanger inside the pit. The additional cost of purchasing and installing this capability is included in this request of budget increase."

A last time-extension to February 17, 1997 with a minor budget revision and small additional funds was needed to allow testing of an asphalt pavement specimen to try out the testing machine and loading frame, later referred to as the "shakedown" test (Section 4.2).

The related grant funded by the Kansas Technology Enterprise Corporation (KTEC) with the matching money from Cardwell International, Inc. to support the project and subsidize the construction and development costs was also extended accordingly. This is described below.

1.3.3 KTEC/Cardwell Project

An Applied Research Matching Fund application was submitted in April 1994 to KTEC by the corporate sponsor, Cardwell International, Ltd., of El Dorado, Kansas in conjunction with KSU. The objective of the application was as follows (excerpt from the Abstract of the subject application):

"The purpose of submitting this applied matching fund application is to obtain financial assistance to construct an Accelerated Pavement Testing Facility on the campus of Kansas State University for the development of an innovative Load Transfer System for Concrete Pavement known as the *X-FLEX*™."

The funds requested from KTEC were to be matched (in the ratio of at least 40/60%) in funds from the corporate sponsor. The application was accepted and an agreement was reached on June

9, 1994 between Cardwell International, Ltd., Kansas State University, and KTEC. The project entitled "Development of An Accelerated Pavement Testing Facility for the Development of an Innovative Load Transfer System for Concrete Pavement:*X-FLEX*" was granted to the University and its industrial partner (KTEC Project #434). The original duration of the project was from July 1, 1994 to June 30, 1995. However, due to the same reason mentioned above, the agreement had to be extended (at no additional costs) to June 30, 1997.

As mentioned before, *X-FLEX* is a slab shear-transfer device invented by a team of KSU professors in the Department of Civil Engineering. The invention was patented in the USA following standard university procedures and under the directions of the KSU Research Foundation. Cardwell International, Ltd., through an affiliate company, had previously provided KSU financial support for the preliminary investigation of the commercial value of *X-FLEX* [Hu *et al.*, 1994]. Based on this initial analytical study and experimental work on small size specimens, the potential for successful marketing was considerable. KSU Research Foundation granted the company an exclusive license to develop and commercialize the technology incorporated in the patent rights. This research and license agreement includes the rights to make, use, sell, and distribute the product both in the US and international market.

The work plan of the KTEC/Cardwell project was as follows (excerpt from the KTEC Applied Research Matching Fund Application, under Methodology and Milestones):

> "Cardwell will make further investment to install a facility at KSU to perform verification tests required to make this device (i.e., *X-FLEX*) marketable. A team from KSU has developed information, plans and design drawings for an APT (Accelerated Pavement testing) laboratory."
>
> "The work plan is shown below:
>
> *Task A*. Renovate and install environmental control in an existing building (Seaton Hall) at KSU. Alternatively, the Dean of the College of engineering is investigating the possibility of construction of a Butler building that will house several anticipated facilities including the APT laboratory.
>
> *Task B*. Design and fabrication of the accelerated pavement tester (frame, wheel loading devices, dynamic mechanism, etc.) by Cardwell International personnel and designers.
>
> *Task C*. Installation of testing equipment in the building at KSU including hydraulic hook-up and mechanical assemblage.
>
> *Task D*. Purchase and installation of the control and monitoring instrumentation including power hook-ups and electronic connections. By this task, the

APT facility should be ready for operation.

Task E. Conduct research according to a detailed testing plan."

As part of the Applied Research Matching Funds application, the corporate sponsor (Cardwell International, Ltd.) prepared both a Commercialization Plan and a Business Plan. The commercialization plan provides detailed information about commercialization of the new technology and the economic benefit of the project. It includes indications on the potential market size of the product as compared to existing or competitive devices, the marketing strategy, and sales projections. The business plan defines the major steps that will be followed by the company to develop manufacture and market the *X-FLEX* System. The first and most prominent step in the business plan was to develop in conjunction with KSU and KTEC the accelerated testing facility. An important component of this plan was to establish technical and economical feasibility of the *X-FLEX* System. This includes (1) a market analysis summary (industry analysis: market segmentation, production and delivery patterns, competition and buying patterns; industry keys to success; and market forecast), (2) a strategy and implementation summary (market strategy: pricing, promotion, distribution, marketing; and sales strategy), (3) a management summary, and (4) a financial plan.

2. K-ATL DEVELOPMENT STAGES

The main effort in this project consisted of designing, constructing and installing specialized equipment for the application of a 178 kN (40-kips) wheel load in monitored environmental conditions. This was done along with other tasks such as designing the lab space, dimensions of the pits, loading frame, driving mechanism, etc. Much of the facility design and specifications were made after an extensive literature survey, site visits, interviews with experts, and study of the available facilities. Perhaps the most important decisions were based on the Advisory Committees suggestions and recommendations.

2.1 Advisory Committee

The KSU Accelerated Testing Laboratory Advisory Committee was formed at the early stages of the project (January 1995) to provide input on the design of the facility and to determine future test needs. This would allow the facility to be used to perform experiments for a number of researchers with common interests and respond to a variety of testing needs. The facility was intended to be of service to state agencies and industries as well.

The Kansas committee members were appointed by the Assistant Secretary and State Transportation Engineer of KDOT. Since its conceptual design, the facility was envisioned as a regional (and possibly national) testing and research center. Therefore, the surrounding states were invited to appoint representatives to the advisory committee. Six states were represented in the committee. The FHWA was also asked to participate in the panel. The latest listing of the committee members is given in Appendix A. Another dozen of corresponding members from the University, the Department of Transportation, and the FHWA showed interest in the activity and were constantly updated about the meetings and the committee proceedings. Several other persons attended the committee meetings as visitors or replacements for excused committee members.

The size of this committee reached seventeen members and included bituminous research engineers, geotechnical engineers, soil and pavement, state bridge engineers, and FHWA experts. Their experience varies from research and design of pavement mixes, binders, soil and subgrade, to bridges and structures, and Accelerated Loading Facilities (ALF). The committee has helped tremendously in the conceptual design of the facility, the selection and design of the equipment, and the different capabilities and features of the laboratory.

The committee formally met six times. However continuous correspondence and telephone and electronic communications took place as part of this activity. The meeting dates in 1995 were February 10, March 7, June 15, and December 14, and in 1996 were April 25, and November 6.

The minutes of the meetings were diligently prepared by the committee chair and were distributed to the committee members and other interested persons. The minutes are available on file for future reference. The committee was dissolved at the ending date of this project.

2.2 Survey of State-of-the Art

The most comprehensive survey of existing full-scale accelerated testing facilities around the world can be found in a report published by the Transportation Research Board (TRB) [Metcalf, 1996]. The report includes the description of thirty five active facilities since 1962 as shown in Figure 1. It also describes several applications of accelerated pavement testing and covers activities in eighteen different countries. These facilities include 5 test roads, 13 circular test tracks, 14 linear test tracks, and 3 full-scale load but small-scale pavement facilities.

The test roads began in the US in 1919 in Arlington, Virginia, where a circular test track was loaded by an actual truck. Other test roads, not necessarily circular, were constructed elsewhere up to 4.8 km (3 miles) long, some of them loaded under normal highway traffic. They made major contributions to the understanding of pavement performance and serviceability. However, they lack controlled environmental conditions and are expensive to operate if acceleration of damage is to be attained through controlled loading.

The circular test tracks have advantages in operating at high speed and can be used to test several sections at the same time. However, except for very large diameter tracks, lateral shear and centrifugal forces (and resulting high tire wear) can be a problem. Also, if one section fails, the performance of all other sections may be affected.

Therefore the decision of the KSU team was to construct a linear track facility. Because the full-scale outdoor testing machine are very expensive, especially when temperature control is desired, the choice was even more limited to an indoor linear test track facility. Among the linear test tracks described in the TRB report, only six are considered indoor facilities (inside housing). These are as follows.

1. Danish Road Testing Machine (DRTM) in Denmark
2. Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland
3. LINTRACK at Delft University of Technology in the Netherlands
4. Minne-ALF (Accelerated Loading Facility) at the University of Minnesota, in Minnesota
5. Pavement Testing Facility (PTF) at the Transport Research Laboratory in the United Kingdom
6. INDOT at Purdue University in Indiana

Another facility, known to the author and referred to in the TRB survey but not shown in the table in Figure 1., is the Pavement Test Facility at the University of Nottingham in the United Kingdom [Brown and Brodrick, 1981]. This and other less than full-scale facilities were not discussed in much detail in the TRB report despite the significant contributions they made to the development of accelerated testing methods and to pavement design and material research.

In this report only the full-scale linear track facilities in the USA (enclosed and outdoor) are summarized.

2.2.1 Enclosed Facilities

As shown from the above, at the onset of this project, only two indoor linear track facilities existed and were operational in the USA: the Minne-ALF of Minnesota and the INDOT facilty of Indiana. Neither of these facilities have the capability of cooling/freezing the slab or applying combinations of mechanical and severe thermal loads. These two facilities are presented below. Since then, only three other facilities, --to the author's knowledge--, have been constructed or upgraded to handle indoor, temperature controlled, sophisticated accelerated testing. The first is Cal/APT, the California Department of Transportation's (CalTrans) Accelerated Pavement Testing program, the second is the Cold Region Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, and the third is the Ohio Accelerated Pavement Load Facility (APLF). These three facilities are also described below.

The Minne-ALF

This facility is located at the University of Minnesota and consists of a single-tire load assembly working on a 4.5 m (15 ft) long by 3.7 m (12 ft) wide test pavement. The equipment is housed in a laboratory that allows partial control of temperature gradients. The testing length is 2.4 m (8 ft) with a maximum load of 107 kN (24,000 lb.) on a single tire, half-axle (expandable up to dual tire, full axle) and speeds up to 90 km/h (55 mph). Such high testing speed (as in many other facilities reporting this magnitude of speed) is obtained not by a rolling wheel assembly but rather by a load propulsion consisting of a rocking arc driven by two hydraulic actuators and a high GPM hydraulic pump. This testing procedure was not considered for the Kansas facility and was therefore disregarded.

The INDOT-APT

This facility is located at Purdue University in Indiana. A detailed description of this facility can be found in [Albers, 1991] and [White *et al.*, 1990]. The wheel load is around 44 kN (10 kips) applied through a single tire or a pair of tires. At an early stage of this project, a team from KSU made several visits to Purdue University to obtain information, plans, pictures, and design drawing of this facility. At the time of the visits, the mode of operation was such that the flexible pavement is cast on a concrete slab with flexible pipes through which hot-water is circulated to warm the pavement from the bottom. The main type of testing is rutting and fatigue of flexible pavement with different asphalt mixes mainly under normal or limited heated temperature conditions.

The Cal/APT

The Cal/APT (CalTrans Accelerated Pavement Testing) program was embarked on its initial 5-year program in July 1994. The program involves a cooperative effort between CalTran, the University of California at Berkeley (UCB), Dynatest Consulting, and the South African Council for Scientific and Industrial Research (CSIR). Following a successful fast-track pilot study project on the Heavy Vehicle Simulator (HVS), developed more than 22 years ago by CSIR, CalTran initiated the 5-year project with a US $5.75 million contract to UCB (CSIR and Dynatest are subcontractors on this project). Two refurbished HVS's were purchased by CalTran (US $1.75 million) under a separate contract. One unit was intended for indoor controlled testing in the APT facility and the other for field testing on the California highway network [Dynatest, 1995].

The Army CRREL

The CRREL (Cold Region Research and Engineering Laboratory) is run by the U.S. Army Corps of Engineers and is one of its kind in the United States and in the world. It is a very large and sophisticated facility but cost of testing pavement testing is far beyond what many state agencies can afford. Originally, the CRREL lab had only the capabilities of heating/freezing pavement in test pits. However, in 1995, the Army obtained an HVS (similar to the South African ones mentioned above) for operation inside the facility to be able to apply up to 200 kN (45 kips), single or dual axles, on the test pits in conjunction with the thermal controlled conditions.

The CRREL was contacted by KSU researchers and information was obtained to add thermal panels (coils) to apply heat or freeze the pavement from the top (i.e. pavement surface). Twelve coils were acquired through the second phase (cost/time extension) of this project by the K-ATL. These are identical to those used by CRREL.

The Ohio APLF

The Ohio Accelerated Pavement Loading Facility (APLF), which is a completely enclosed facility, was opened in June 1997 at Ohio University in Lancaster. The facility (US $1.65 million) was funded by the Ohio Board of Regents, Ohio University and Ohio State University. The 380 m^2 (4100 sq. ft) building comprises a 298 m^2 (3200 sq. ft) environmentally controlled test area which includes the loading mechanism (single wheel), control, and monitoring equipment. Load can reach up to 133 kN (30,000 lb.) and temperature can range from -12°C to 43°F (10°F to 110°F) and air humidity and soil moisture can be controlled. The test pit is 13.7 m × 12.2 m × 2.4 m (45 ft × 40 ft × 8 ft.) No experiments or test results have been reported yet from this facility.

2.2.2 Outdoor Facilities

In addition to the HVS which can be used either indoor or outdoor as used by CalTrans or the

Corps of Engineers, the other types of outside accelerated testing machines are the Accelerated Testing Facility (ALF) and the Texas Mobile Load Simulator (TxMLS). These were much beyond the Kansas State budget range but are presented here for reference.

The ALF's

The ALF, designed in Australia, is now operated at five locations by four organizations. This testing methodology was first commissioned in 1983 at the Australian Transport Research Center (US $1 million). The FHWA acquired two ALF's. The first was installed at the pavement testing facility at Turner-Fairbank Highway Research Center in McLean, Virginia (US $1.1 million) in 1986, and the second in 1995. The Chinese ALF (US $1 million) was installed at the Research Institute of Highways in Beijing in 1990. The last, the Louisiana Department of Transportation's ALF (US $ 1.8 million) was installed at the Pavement Research Facility at Baton Rouge in 1994.

The ALF applies loads up to 78 kN (17,600 lb.) through a dual-tire single-wheel assembly to a test length of 12.2 m (40 ft) at a constant speed of 20 km/h (12.5 mph) which is considerably higher (about double) than most indoor accelerated testing machine with rolling wheel assemblies. It has a unique feature of transverse movement of the loading mechanism which can cover a 1.4 m (4.5 ft) wide path. When it was first designed its particular capability was that it applies load in one direction only (similar to one-way traffic) as opposed to the other testing machines at the time which were driven by a cable and apply load on both paths (forward and backward). It is a transportable machine for use on in-service highways or on specially constructed test pavements. Both modes of operation have been used for the five machines.

The disadvantage of the ALF is that it is expensive to construct (also patented), expensive to operate, and does not offer environmental control testing such as heating and freezing. Housing the whole machine would be very costly. The FHWA has recently modified its ALF to include only heating through radiant heaters enclosed around the test area or the wheel path. This method of heating is the same as what the HVS has always had. Cooling or freezing can not be accomplished. At the time of writing this report, similar radiant heaters are being acquired and installed at the Kansas facility.

The TxMLS

The TxMLS (US $2.5 million) was commissioned in 1995 by the Texas Department of Transportation. It is a transportable linear device capable of applying six single or dual-tire bogies with tandem axles loaded up to 187 kN (42,000 lb.). Test speed is similar to the ALF, i.e. 20 km/h (12.5 mph). The pavement section under the wheel path is 8 m (26 ft) long and transverse tracking (wander) is 610 mm (24 in). It also has a fully enclosed chamber around the wheel path for environmental control.

The loading mechanism follows a model tried in Australia in 1961, in which the wheel assembly leaves the pavement when it reaches the end of the track, is raised up, inverted, and returns (up-side-down) on some type of conveyor belt until it goes back to the beginning of the track where it is redressed and lowered down to hit the pavement. The bogies therefore move always in the same rotational direction (clockwise or counter-clockwise). This required no acceleration and deceleration at the beginning and end of each trip and allows the wheel load to travel at much higher speed. It can apply an average of up to 8800 passes per hour.

Two of the bogies are powered by electric motors with a belt drive to one axle and the remaining four are trailing bogies, which to some extent simulate normal traffic where not all truck axles are drive axles. Overall it is the most recent and most elaborate accelerated testing machine to-date, but also the most expensive of all.

2.3 Construction of the Kansas Facility

Whereas funds from Cardwell and KTEC were specified for the testing machine and the implementation of the *X-FLEX* joint system, funds from KDOT were primarily designated towards the acquisition and installation of the thermal capabilities. However a new and special building had to be constructed to allow for all the details and features needed. Funding for the building project was provided by the College of Engineering at KSU through private donations.

2.3.1 Physical Space

A new building of about 651 m^2 (7000 sq. ft) was planned and designed to house the ATL. The floor plan is shown in Figure 2. It consists of 537 m^2 (5775 sq.ft.) of test space and about 114 m^2 (1225 sq.ft.) of office space. The test space includes the main test area of 22.9 m×18.3 m (75'×60') or about 418 m^2 (4500 sq. ft) with the test pits at the center, about 93 m^2 (1000 sq.ft.) for a FWD state calibration room, and about 26 m^2 (275 sq.ft.) for the electrical and mechanical rooms. The mechanical room is where the pavement cooling and heating equipment were to be installed.

Initial plans presented to the College of Engineering administration in 1994 were to build a 6.1 m×6.1 m (20'×20') pit for the ATL and 93 m^2 (1000 sq.ft.) of space for the FWD. Then the idea of thermal control was developed and the need for the environmental pit became obvious. Following plans to install pipes buried in the subgrade to freeze or heat the soil, the need for an adjacent pit or trench was raised. Later, it was suggested to also have thermal capabilities from the surface using the plate coils, and therefore the need for the second glycol system of pipes, air separators, expansion tanks, etc. The last pit 3.7 m×6.1 m (12'×20'), similar but narrower than the large middle pit was added to accommodate an earthquake research project with the possibility of using this last pit for additional pavement testing, or use it in conjunction with the middle pit to form a 6.1 m×9.8m (20'×32') pit. This larger size could accommodate testing of bridge components (decks, girders, expansion joints, etc.) up to 9.8 m (32 ft) span if necessary. For this reason a 0.305 m (1 ft) wide ledge was constructed around the 6.1 m×9.8 m (20'×32') area at mid-height of the pit wall so that bridge or structural supports may be mounted on it.

2.3.2 Construction Cost

The cost breakdown to construct and equip the lab are shown in Appendix B. The contributions of KDOT came from Federal State Planning & Research (SP&R) funds. These were used to support the research team and lab personnel, and to purchase and install the thermal equipment.

The cost for the construction of such a building as described in the previous section was beyond the original estimates. This is partially attributed to the additional details for the floor and pit walls and the same many improvements that also drove up the budget needs of the KDOT project, as described in previous sections of this report. It was therefore decided to proceed with a reduced size of the building as shown in Figure 3. This would allow the construction of the same test area needed but eliminate the space for offices, conference room, etc., which is designated on the Figure as future expansion. Other items also had to be cut back such as the loading dock, concrete driveways and curbs, and the sidewalk in front of the building. With the available funds (raised up to $344,000) the second plan would allow the construction of the 537 m^2 (5,775 sq.ft.) needed to test pavement, conduct the earthquake research, and accommodate the FWD calibration space need. This would allow the KSU team to carry out the research and fulfill its obligation towards the sponsors and the industrial partners. The construction of the office/conference space was postponed till further funds are raised by the Dean of the Engineering at KSU.

When additional donations were received (about $50,000), priority was given to the installation of a 10T- capacity overhead crane in the building and the purchase of a forklift to the lab, both most essential for material and equipment handling. Other funds from the Department of Civil Engineering were used to purchase many items such as metal arc welders, miscellaneous equipment and supplies, and landscaping. Presently, funds are being sought for the addition of the office space and by that complete the building project as originally planned.

2.3.3 Development Stages and Dates

Originally, the building that would house the ATL equipment consisted of either a renovated existing building at Kansas State University (namely Seaton Court) or a new construction that would be within, or close to, the KSU campus in Manhattan. Both options were investigated and the idea of renovating Seaton Court was dropped. Several tentative plans and drawings for a new building were prepared and studied in the second half of 1994. By the end of 1994, the construction site for the new building was selected. The location is on a KSU land in the Industrial Park located at the East part of Manhattan. The building was to be constructed south of an existing building presently used by the Advanced Manufacturing Institute in the College of Engineering of KSU.

Final design drawings, site plans, floor plans, and construction details were prepared for approval by the Division of Facilities at KSU. The request for construction of the new building was approved by the Kansas Board of Regents in January 1995. Detailed construction drawings were prepared by the KSU Division of Facilities and contractors were contacted to negotiate construction costs. Several revisions were made to the building design and construction plan to suit the research needs and fit the building budget. Complete preliminary design drawings were prepared in March 1995 and later in May, 1995, and the final executable plans were signed and approved by the University architect in July 1995. Shortly afterwards, a contract was signed with the general contractor and construction began in the Fall of 1995. Concrete work started for the bottom of the pits (Figure 4), followed by the pit walls (Figures 5 and 6), and the building foundations. Work on the concrete floor of the main lab space started in December 1995.

The testing apparatus tracks were delivered by Cardwell International on January 5, 1996 and installed in the floor system on January 8 and 9. All concrete work including casting the floor was completed on January 11, 1996. The building steel frame (beams, columns, etc.) was delivered at the site on January 22 and erection started immediately afterwards.

The fabrication of the loading assembly and test frame was completed in April 1996. The apparatus was delivered and installed in the ATL building on April 11, 1996. At that time it had all major mechanical components including the driving motor, belt, air compressor, hydraulic system, and control board. A few minor items, such as the end-springs, wheel guides, and limit switches, were added later to the machine. The mechanical and electrical hook-ups were completed within about 5 months.

The dedication of the facility including the ATL took place on April 12, 1996. KTEC board members, members of the ATL advisory board, and KDOT transportation officials were invited to the ceremony. Visitors and guests including industry representatives were impressed by the facility and the test equipment and apparatus. The facility was opened from 2:00 PM to 6:00 PM (open house). The dedication ceremony started at 4:00 PM and lasted about 30 minutes.

2.4 Progress Reports

Progress reports were sent to the KDOT Project monitor as work was being performed. The dates when the progress reports were sent are as follows: (1) November 3, 1994; (2) February 3, 1995; (3) January 31, 1996; (4) April 15, 1996; (5) July 23, 1996; and (6) September 20, 1996. Additional informal reports were made via electronic mail, telephone conversations, or as presentations to the Advisory Committee.

Other progress was reported during a presentation made at the 86th Annual Meeting of the Mississippi Valley Conference of AASHTO, in Chicago [Melhem, 1995]. The talk was well received by the audience and a number of good comments were given. Also on April 11, 1996, Dr. Melhem made a presentation on the ATL project at the 78th Kansas Transportation Engineering Conference in Manhattan. During the presentation, he invited the audience to come to the open house and attend the dedication ceremony the next day. The talk which lasted from 4:05 p.m. to 4:35 p.m. was well accepted by the participants.

App. B Index	Acronym	Location	Year Commissioned	Nr. Tests Reported	In Use 1995	Initial Cost ($)	Annual Costs ($)
	TEST ROADS						
B1	MnROAD	Minnesota	1993	40	yes	2,500,000	500,000
B2	NARDO	Italy	1979		no		
B3	PTI	Pennsylvania	1971	17	no		
B4	PWRI	Japan	1979		yes	500,000	200,000
B5	WesTrack	Nevada	1995	new	yes		
	CIRCULAR TEST TRACKS						
B6	C - TIC	Saskatchewan	1978	3	no	400,000	
B7	CAPTIF (1)	New Zealand	1987	20	yes	300,000	
B8	ISETH	Switzerland	1979			750,000	
B9	IUT	Illinois	1963		no		
B10	JHPC	Japan	1979		yes		
B11	LCPC	France	1978	130	yes	5,000,000	800,000
B12	Road Machine (2)	United Kingdom	1963		no		
B13	RRT	Romania	1982	40	yes	420,000	100,000
B14	Shell	Netherlands	1967		no		
B15	S - KSD	Slovakia	1994		yes		
B16	UCF	Florida	1988		yes	250,000	
B17	UNAM	Mexico	1970	100	yes	480,000	190,000
B18	WSU	Washington	1965	12	no		
	LINEAR TEST TRACKS						
B19	ALF	Australia	1984	158	yes	1,000,000	600,000
B20	FHWA - PTF	Washington D.C.	1986	25	yes	1,100,000	275,000
B21	RIOH-ALF	China	1990	16	yes	1,000,000	
B22	PRF - LA	Louisiana	1995	new	yes	1,800,000	200,000
B23	DRTM	Denmark	1973		yes	200,000	100,000
B24	EPFL	Switzerland	1977				
B25	HVS	South Africa	1971	500	yes		
B26	CAL-APT	California	1994	new	yes	1,700,000	1,200,000
B27	LINTRACK	The Netherlands	1991	2	yes	1,000,000	164,000
B28	Minne-ALF	Minnesota	1990	new		200,000	
B29	PTF	United Kingdom	1984		yes	1,700,000	
B30	INDOT/PURDUE	Indiana	1992	32	yes	140,000	49,000
B31	TxMLS	Texas	1995	2	yes	2,500,000	
B32	CEDEX	Spain	1987	new	yes	2,100,000	
	OTHER						
B33	BASt	Germany	1963	15	yes		
B34	MSU	Michigan	1990		no	100,000	
B35	PHRI	Japan	1969				

Replaced earlier facility commissioned (1) - 1967 (2) - 1933

Figure 1. Summary of Accelerated Testing Facilities in the World
(Taken from [Metcalf, 1996], p12)

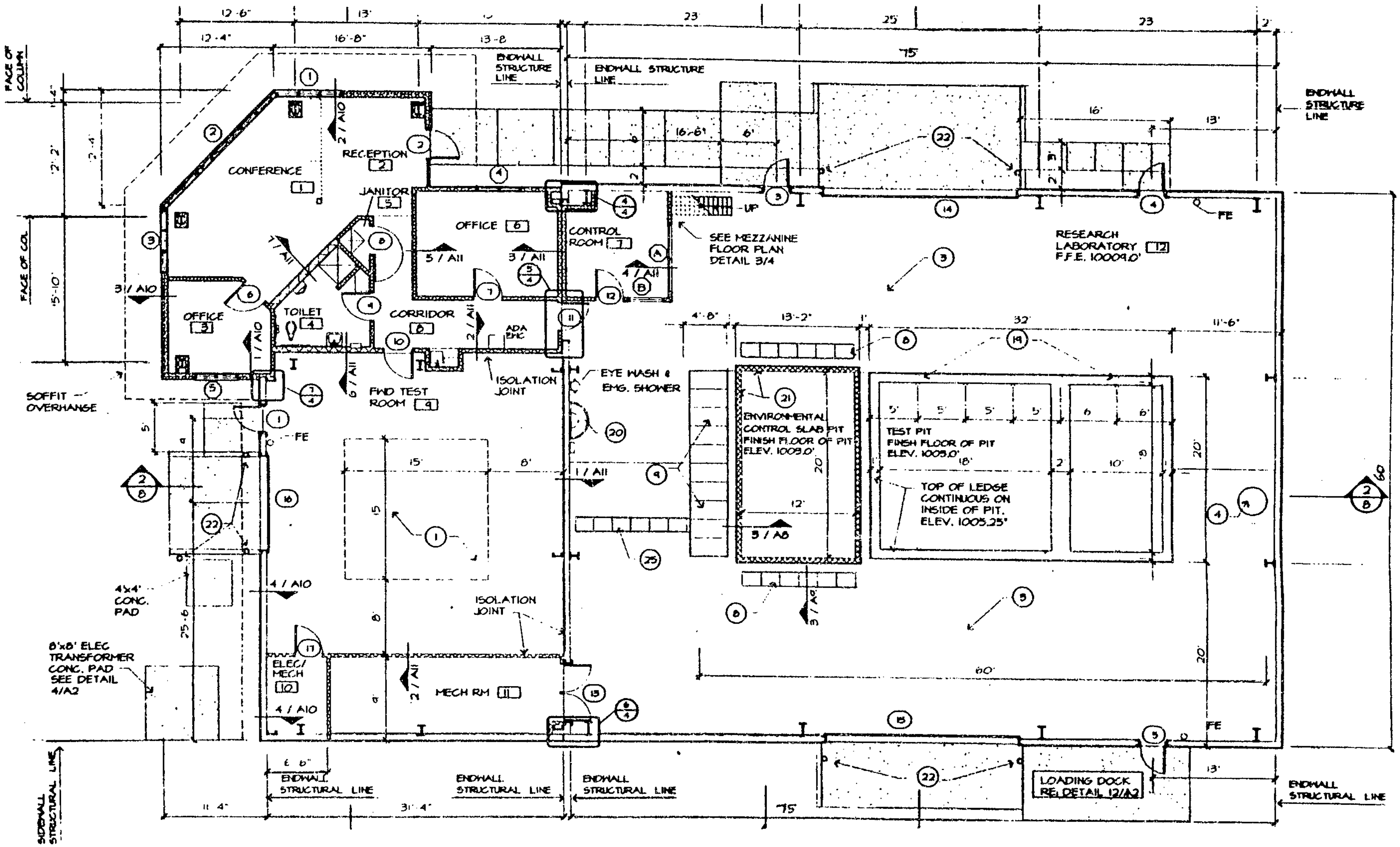

Figure 2. Original Floor Plan of the ATL Facility
(Drawing provided by KSU Division of Facilities)

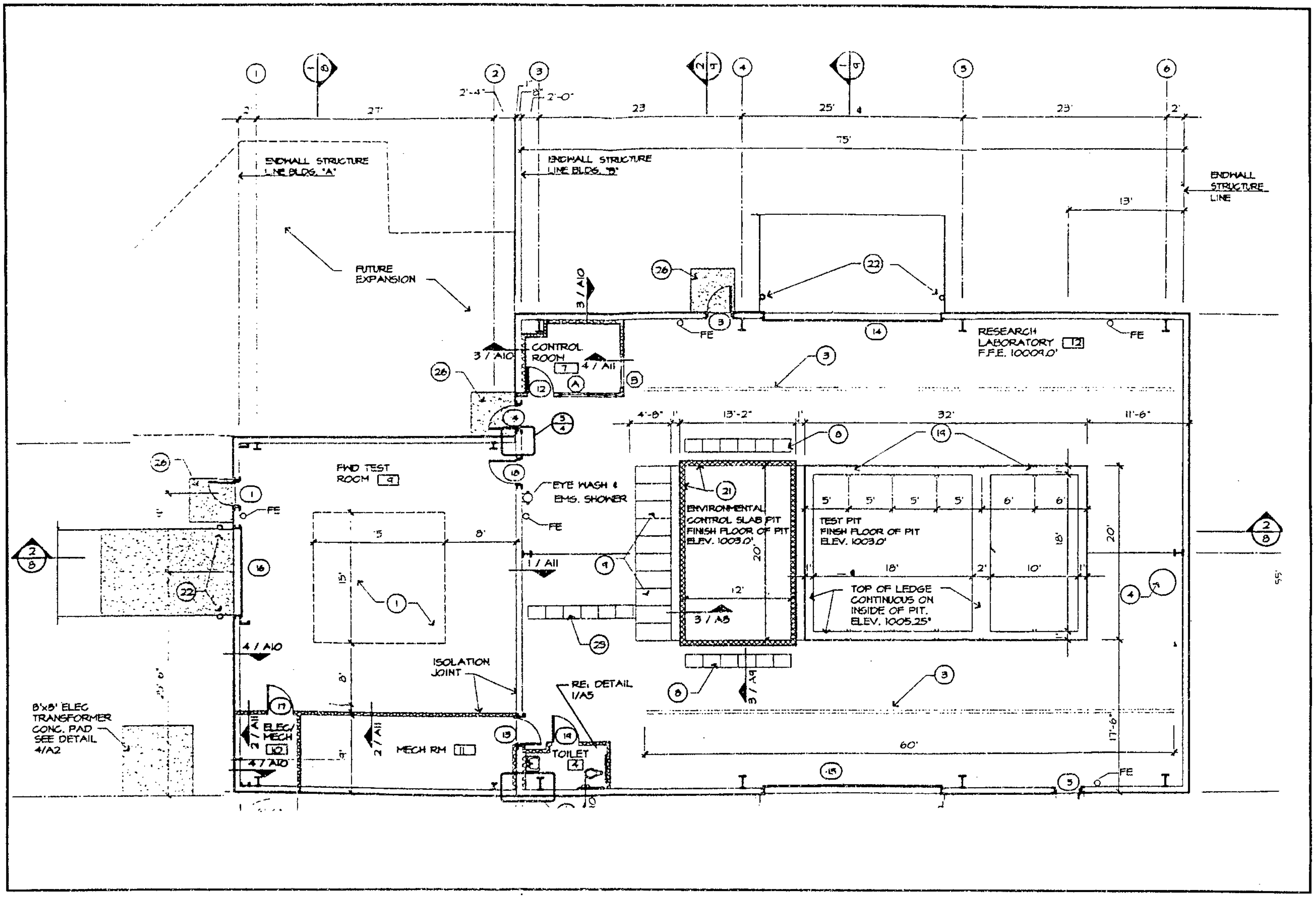

Figure 3. First Phase of the ATL Facility with Test Space
(Drawing provided by KSU Division of Facilities)

Figure 4. Construction of the Pits Foundations

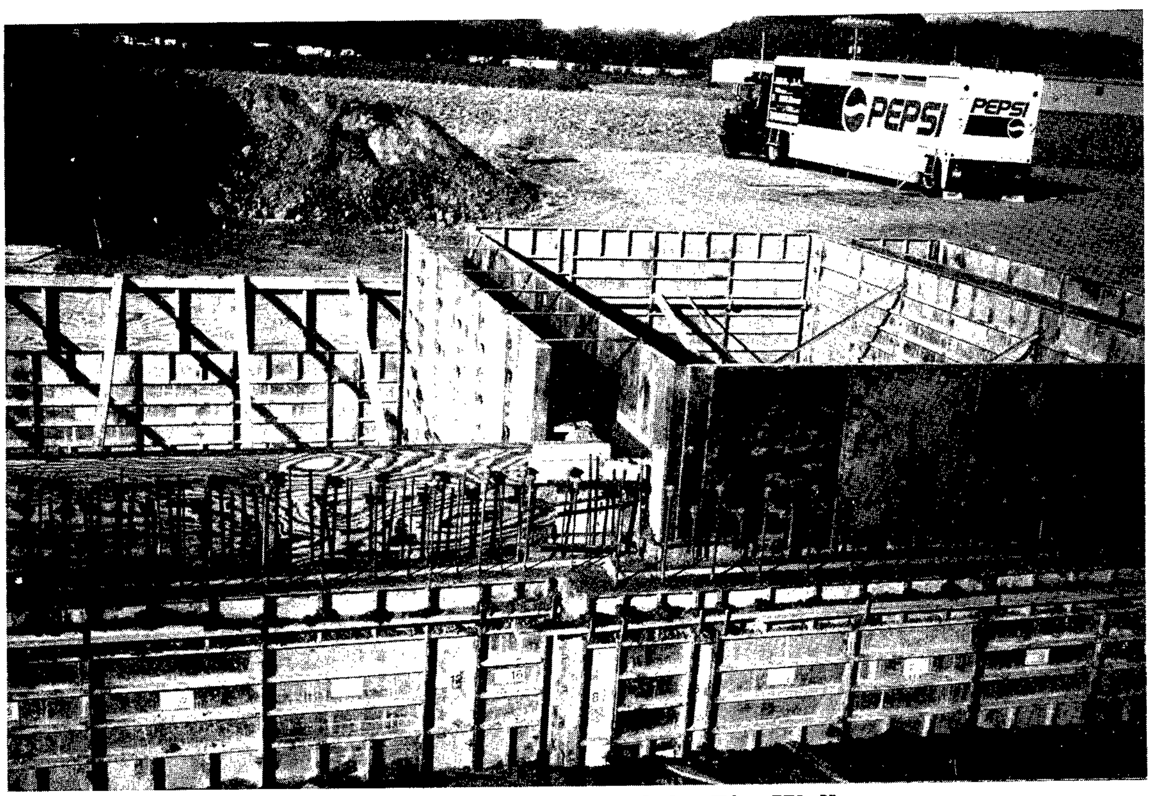

Figure 5. Construction of the Pits Walls.

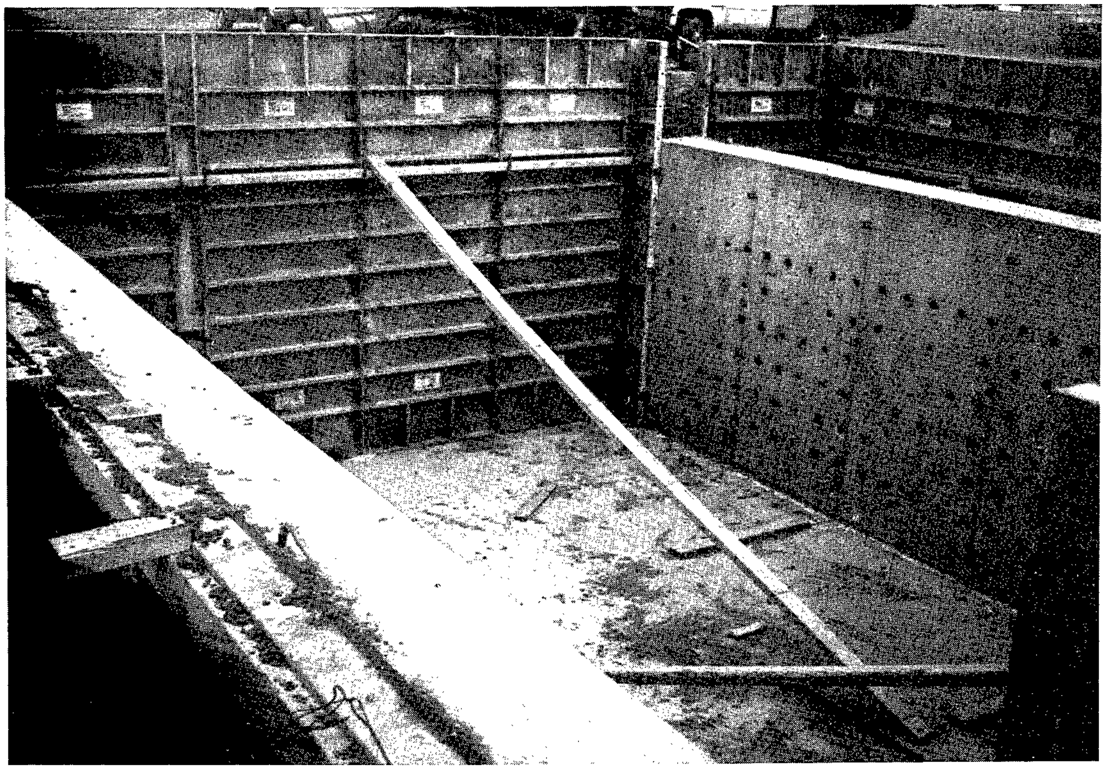

Figure 6. Concrete Walls of the Environmental Pit

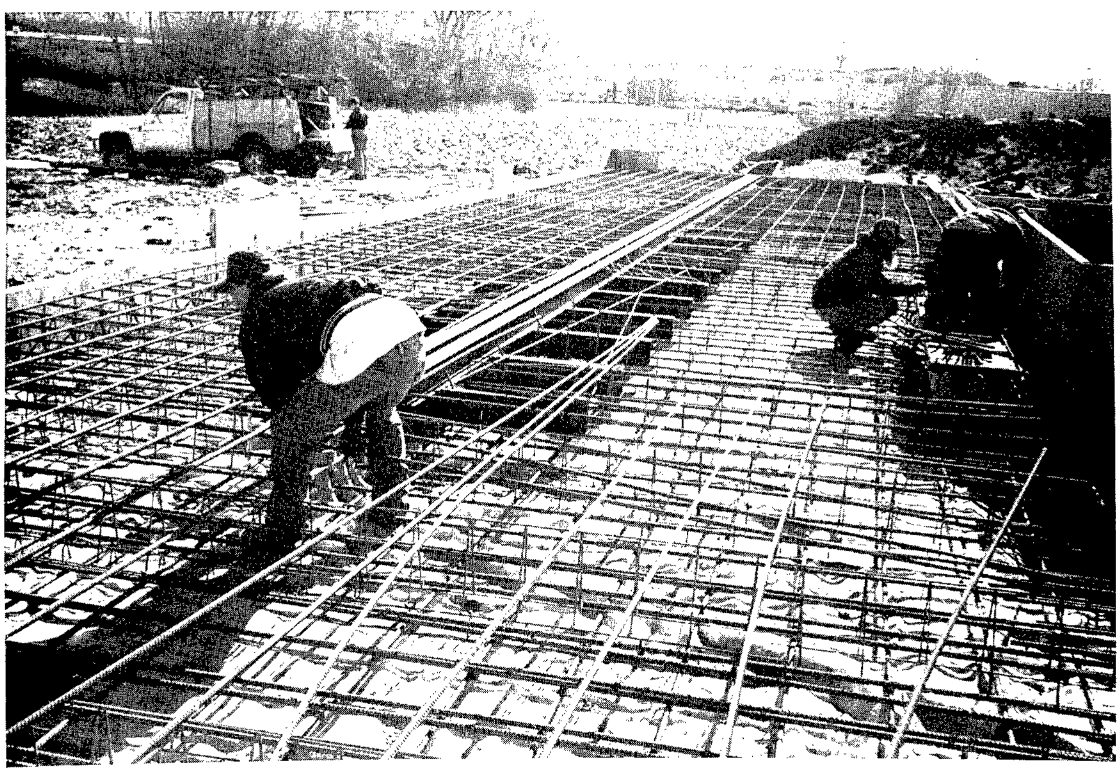

Figure 7. Reinforcement of the 18" Floor and the Testing Machine Tracks

3. DESCRIPTION OF THE FACILITY

The Accelerated Testing Lab (ATL) is part of a larger facility called the "Kansas Testing Laboratory for Civil Infrastructure and Highway Research." The facility also includes the Kansas Falling Weight Deflectometer (FWD) state calibration room, and a shake-table for earthquake engineering research. The ATL is the main and largest part of the facility. The FWD room is adjacent (North) to the main testing lab and the shake-table is installed in an empty test pit, similar to those filled with compacted soil and used for pavement testing.

3.1 Laboratory Space and Test Pits

The laboratory area consists of about 537 m^2 (5775 sq.ft.) of test space which includes the main test area of about 418 m^2 (4500 sq. ft) with the test pits at the center, about 93 m^2 (1000 sq.ft.) for the FWD calibration room, and about 26 m^2 (275 sq.ft.) for the electrical and mechanical rooms. The mechanical room is where the pavement cooling and heating equipment is installed (see Figure 3).

Two 1.8 m (6 ft) deep test pits are located in the center of the lab. The main pit is 9.8 m×6.1 m×1.8 m (32'×20'×6') and can be partitioned into four 1.5 m (5 ft) and two 1.8 m (6 ft) wide subdivisions if it is desired to test different soil types, degree of compaction, or water table conditions. Soil can be removed from part or all of this pit which can then be used for testing bridge components, composite decks, and expansion joints. Next to this pit is an insulated environmental pit which is 6.1 m×3.7 m×1.8 m (20'×12'×6') and which has metal (stainless steel) U-tubes buried in the soil underneath the specimen and in which a glycol solution will be circulated to freeze or heat both the subgrade and the slab. Adjacent to the environmental pit is a 1.2 m (4 ft) wide access pit. It is used to allow easy access to instrumentation and heating/cooling U-tubes. It currently includes the main headers used to distribute and collect the glycol solution to and from the U-tubes. The headers have ball-valves on the supply and return sides of each of the U-tubes.

A longitudinal section through the floor plan is shown in Figure 8. Transverse sections through the main pit and the environmental pit are shown in Figures 9 and 10, respectively. The floor is 457 mm (18 in.) thick throughout the ATL area and is structurally integral with the pit walls to insure water tightness and avoid differential settlement. Figures 9 and 10 also show floor beams and rails buried in the concrete floor on both sides of the pit. These are the guides for the testing frame and provide attachment (tie-down) and downward reactions against uplift when the load is applied to the specimens (also see Figure 7).

The floor design includes provisions for confining the edges of a concrete slab specimen that would expand or contract under varying temperature in the environmental pit. For instance, when the test slab is frozen, it will tend to contract. In a real-life situation, this will be a section of a continuous concrete highway, and the section under consideration will be prevented from contraction in the direction parallel to the highway centerline. For this reasons tie rods with bolts and screws/coupling will be used to attach the test slab to the pit vertical walls. The pit is designed accordingly and sleeves at the top of the walls are provided as shown in Figure 11. In addition to providing anchors to the slabs, the recess in the concrete floor on the East and West of the environmental pit is also used to drop the distribution header (East) and collector headers (West) for the upper (surface) heating/cooling coils (see Figure 25).

3.2 Test Frame and Loading Devices

3.2.1 Test Frame

The testing frame is shown in Figures 12 through 15. The main girders (two) and columns are made of W30×99 rolled beams. The frame span is 12.8 m (42 ft) center-to-center. This will allow the carriage to get off the specimen before it goes back in the opposite direction. At the end of the travel distance, an energy absorption/release system (air springs) helps transform the kinetic energy of the carriage into potential energy in the springs, and than back to kinetic energy redirecting the carriage in the opposite direction. The air springs are filled through an air-compressor installed on the carriage and controlled through a set of valves and pressure dial gages.

The elevation at which the girders are connected to the columns may be changed in the future if it is desired to have a different carriage or wheel assembly system, or when an overlay is constructed such that the surface of the pavement is higher than that of the laboratory floor. This might be necessary if a different loading system with impact (pulse loading) capability or a different size carriage is required. The design is such that the beam/column rigid connection can be altered at 76 mm (3 in.) vertical increments.

3.2.2 Wheel Load Assembly

The wheel assembly consists of a tandem axle assembly (TAM) with air suspension system (air-bags). The wheel assembly (carriage) is an actual bogie from a standard truck as shown in Figure 16 and 17. The automatic control of the air-suspension system provided by the truck factory was eliminated and replaced by a manual air-pressure control. Loading of the axle assembly is therefore through varying air pressure. The same compressor that feeds the end air-springs is used to charge the air bags (suspension system). The wheel load versus air pressure relation was verified for each set of wheels using a portable weigh-scale of the local Highway Patrol authority (Troupe C, Salina, Kansas). The air-bag pressure was increase linearly at 69 kPa

(10 psi) increments and the load was recorded until it reached 178 kN (40,000 lbs), including the self weight of the bogie and reaction frame.

The arrangement allows the system to load one or both axles as desired. One or more pairs of tires may be replaced by a super-single if a test requires so. A pressure tank (accumulator) was added on each axle of the bogie to absorb the shocks in the line when the carriage jumps on and off the specimen or when excessive rutting of the pavement may cause large pressure fluctuations. Normally the system would be loading in both direction as the wheel assembly moves back and forth. However, one way traffic simulation can be achieved through a hydraulic system as described below.

A set of two hydraulic cylinders were added later on each of the carriage axles to lift the wheels up when needed. A hydraulic pump also mounted on the moving carriage is used to activate these cylinders. The wheels can be lifted either manually or automatically. When a one-way traffic simulation on the specimen is required, the automatic mode will cause the eight wheels to be lifted off the ground when the carriage reaches the end of the track until it goes back to the starting position. An electronic signal is given to the pressure valve on the hydraulic cylinders to lift the axles up and later to let them down on the following load cycle. The manual mode is used when it is desired to lift the axles up at all times, such as when the whole test frame needs to be moved across (or on and off) the specimen.

To move the reaction frame, a special mechanical arrangement is provided at the ends of the frame to set the whole frame (with the tires off the ground) on metal wheels that roll on the East and West tracks. Each track consists of two steel S 6×17.25 beams (side by side with two inches spacing) embedded in the concrete floor and secured with 1727 mm (68 in.)-long cross beams (spreader beams, same size) at 0.92 m (3 ft) interval. Half inch rebar bracing is added to insure straightness. The floor tracks are shown in Figures 18 and 19 (also refer to Figure 7). The reaction frame is moved across the laboratory space using a forklift or the overhead crane as a pushing/pulling device. Accurate positioning is achieved manually with a pry-bar.

The TAM is moved back and forth along the track using a wide and flat conveyor belt driven by a 20 HP variable speed electric motor. The electric motor (480 V, 3-phase) reverses direction every time the carriage reached one end or the other of reaction frame. An electronic control (ABB Drive Model 601) is used to control the speed, count the number of reversals, and shut off in case of emergency failure (see Figure 15). A set of limit switches and optical sensors provide the necessary signal to the electronic controller to stop the motor (coast) or run in the opposite direction (reverse).

The speed of the wheel assembly is about 11.3 km/h (7 mph), constant over the minimum distance of 5.5 m (18 ft) at the middle portion of the 12.8 m (42 ft) track, preceded by an acceleration from zero speed at the start of the track and followed by a deceleration to a complete stop at the end of the track. It takes the wheel assembly between 10 to 15 seconds to complete a full cycle (two-way travel). The fastest safe operating speed achieved was at 80% of the maximum motor capacity at which the wheel assembly takes 11.5 second to complete a full (two-way) cycle. This corresponds to 5.2 cycles per minute or 313 cycles per hours. If loading is applied on both the forward and backward truck passages, this will produce 626 load repetitions per hour. At this rate, the average speed of the wheels axles is 5.6 km/h (3.5 mph) over the total travel distance of 9.1 m (30 ft) whereas the constant speed on the middle portion, over most of the pavement slab, is about 11.3 km/h (7 mph). These speeds may be changed by varying the power output from the driving electric motor. Also changing the pressure in the end air-springs will affect the time taken by the wheel carriage to reverse direction and therefore the overall load cycle period.

In general the carriage could accomplish the following load arrangements: (1) tandem axles with dual wheels or a total of 8 wheels, (2) single axles with dual wheel or a total of 4 wheels, or (3) tandem axles with super singles or 4 wheels, and (4) single axle with super single wheels or 2 wheels. In all cases, the maximum total load on the wheel assembly will be 178 kN (40,000 lbs). However, the best performance would be obtained when using the tandem axles (with dual or single wheel) so that no load eccentricity would result on the bogie from applying load on only one axle.

As this loading assembly was designed and fabricated for the first time and is a one-of-a kind device, several modifications were to be expected. During the November 1996 meeting of the Advisory Committee, it was suggested to perform a shakedown test to check out the experiment before a major testing program was started. This would demonstrate that the equipment can work as expected. Subsequently, KDOT developed a quick test project that was conducted using the wheel load assembly. This experiment is described in Section 4.2. In addition to some interesting results from the experiment, this test led to several system modifications to improve and optimize the performance of the testing machine. For example the electronic control (ABB Drive) Model 500 had to be replaced with a Model 601 unit to perform correct reversal of direction of the electric motor.

3.2.3 Pulse Load System

By the end of June 1996, Cardwell Concrete Systems, a subsidiary of Cardwell International Inc., had completed a number of tests on small scale specimens 914 mm×1829 mm×229 mm (36"×72"×9") with the *X-FLEX* system as well as steel dowels. A load frame was used to apply repetitive loads in addition to tension that simulates the open joint condition. The specimen supports simulate a faulted pavement condition. These tests were discussed in detail at the December 1995, April 1996, and November 1996 meetings of the Advisory Committee. In general, results from these tests revealed the need for a more detailed study on the fatigue strength of the PCCP joints with *X-FLEX*. At this time, Cardwell was investigating alternate shear transfer devices such as fiberglass dowels, stainless-steel dowels, and other shapes of the *X-FLEX*.

It was therefore decided to conduct additional fatigue tests on a full-width section of the concrete slab with *X-FLEX* using cyclic loads applied at the joint using an MTS system with hydraulic actuators. This would give significant insight on the fatigue behavior of the shear transfer device even though it does not exactly simulate the moving wheel effects. The usage of hydraulic actuators allowed the application of a very large number of load cycles (several million) in a relatively smaller time, compared to the wheel loading. The pulse load system (thumper) was fabricated by Cardwell and delivered to the ATL later in the year.

Due to the tremendous delay of the PCCP testing, and after the preliminary small scale tests revealed that several million load applications would be needed to fail any of the PCCP joints, testing of the rigid pavement using the wheel load assembly was obviously not possible. The pulse load system was therefore solely used to test the concrete pavement at the ATL. Tests were performed according to Cardwell needs to correlate data with the small scale test specimens performed in El Dorado. The setup of the concrete test is described in Section 4.3

The pulse load system consists of a two actuators (cylinders) activated by a hydraulic power supply (pump) and positioned across the PCCP joint such that each actuator applies the load on one side of the joint. The pump provides constant pressure through the hydraulic fluid (oil) but a servo-valve directs the flow repeatedly between the two actuators in an alternating fashion, such that when one cylinder is down, the other one is up. This results in a rocking action on the two half-sections of the pavement simulating the passage of a truck over the joint. The cycles are produced by an oscillating signal generated an electronic device (Omron) that includes a timer, relay, and cycle counter. The speed of the oscillations (frequency) can be monitored by proper adjustment of the electronic device.

To apply the load on the pavement, the same reaction frame is used to support the pulse load system. The wheel carriage (bogie) is moved to one end of the frame (East end) to make room for the pulse load system at the midspan of the frame. The actuators are attached to cross beams that, in turn, are bolted to the bottom flange of the frame girders as shown in Figure 24 (also see Figure 29 in Chapter 4). The pulse load system is painted yellow whereas the reaction frame is blue. Actually in order not to cause any damage to the frame flanges, the beams are bolted to the rails that are attached to the girder bottom flanges. The system was designed and fabricated by Cardwell Concrete Systems.

Unfortunately, the steel beams (cross yellow beams) were not properly designed for the large number of repetitive loading needed for the tests, and fatigue cracks occurred several times at the fillet welds. These welds were repaired a number of times in order to complete the desired number of cycles for the experiments.

The maximum pressure used in the hydraulic lines was 11,713 kPa (1700 psi) which resulted in 178 kN (40,000 lbs) alternating between the two cylinders. The optimum test speed was found to be at the signal frequency of 5 Hz (or period of 0.2 sec). The timer also causes a load reversal which oscillates between the two jacks. Therefore, each complete load cycle consists of two load applications, one on each cylinder, resulting in 2.5 load cycles or 2.5 simulated truck passages per second. A truck passage or a complete load cycle is here called "load repetition".

Higher speeds could be attained but produced excessive vibrations in the frame and frame components. Since the signal is basically a square wave, as opposed to a haversine, slower speeds would also result in the same pulse load and same level of noise and vibration but at slower rate, which was not necessarily any better than the optimum speed 2.5 repetitions per second.

3.3 Heating and Cooling System

The temperature control equipment consists of a boiler for heating and a chiller system for cooling or freezing. They both use the same ethylene glycol-based fluid that circulates in the thermal coils to heat/cool the pavement slab and/or subgrade. A set of control valves on the supply and return lines directs the solution to either the boiler or the chiller depending upon the test requirements. The boiler is natural gas fired and is a watertube type (RITE Model 48LL). The chiller system consists mainly of two Bohn compressor/receiver assemblies (Model RS 2700 L6, 460V/3, two-tier rack) that use R404a as refrigerant, a chiller barrel (DXT1208 Acme), and an evaporator condenser (JC 46 Recold, 460V/3) which is an outdoor unit. The boiler and circulating pumps were purchased from Wichita Burner, Inc. in Wichita and the chiller system from General Heating & Cooling Co. in Kansas City. The complete system was designed by a local engineering firm in Manhattan, and was installed and hooked up by a certified contractor from Topeka (see Appendix C).

The heat transfer properties of the cooling/heating system including the diameters of the pipes, refrigerant needs and cooling capacity, heat exchanger pattern and system configuration were studied and designed carefully. Several investigations were necessary to optimize the system configuration with respect to needs for cooling time, frequency of temperature cycles, and temperature ranges. The original system is depicted in Figure 20. Both the chiller and boiler use a 55% ethylene glycol solution that circulates in a piping system buried in the soil (subgrade) under the pavement as shown in Figure 21. Temperature ranges between -23°C and +66°C (-10°F and +150°F).

The depth of the pipes in the subgrade will determine how much of the soil underneath the pavement will need to be thermally controlled. To add more flexibility to the testing facility, it was decided to make the elevation of the heat exchanger (piping network) variable by having six lines of holes at 8 inches intervals (vertically) so that when soil is removed from the pit, the pipes can be installed at a different depth. These are shown in Figure 10 in elevation and in Figure 22 from a cross-sectional view (also see Figure 6). It was later decided to use stainless steel tube instead of steel pipes for the heat exchanger. On any certain vertical level, the tubes are evenly spaced horizontally at 203 mm (8 in.) intervals. This will assure a uniform temperature distribution in the subgrade and pavement. In the present initial position, the U-tubes (17 units) are installed at the third row of holes from the top, i.e. at 914 mm (36") down from the lab floor level).

The environmental and temperature control features were originally designed to allow the pavement to be heated or cooled from the bottom through pipes embedded in the subgrade. However, the Advisory Committee recommended that the environmental controls should have the maximum possible flexibility, and the capability of heating and cooling from the top through thermal panels on the surface was suggested. This would duplicate the usual natural conditions and allows the flexibility to control the temperature gradient through the pavement and subgrade. This would require provisions for circulating the glycol fluid independently through thermal panels (stainless steel plate coils) connected with flexible pipes so that pavement can be cooled/heated from the top down, and therefore the need for additional funds and time. This method is used at the CRREL facility of the U.S. Corps of Engineers, as discussed in Section 2.2.1. This will also allow the testing of cold pavement on an unfrozen subgrade condition. A strip on the surface of the specimen can be exposed to allow for the wheel load to travel on the heated/cooled pavement after is has been heated or cooled.

It was therefore decided to proceed with the dual system as recommended by the Advisory Committee for the great flexibility not only to heat and cool from both top and bottom, but also to specify the temperature of both the pavement surface and the subgrade, and hence the ability to control the temperature gradient through the pavement. Additional funds were provided by KDOT and approval from KTEC was obtained to use, for this purpose, part of the funds provided through the Applied Research Matching funds. The plate coils acquired are shown in Figures 23 and 25. The acquisition of the plate coils (heating/cooling panels) went through an open bid process. Three producers showed interest in providing the plates: Techmark, Tranter, and Mueller. Although not the lowest bid, Techmark was selected because of the highest quality and the finest fabrication process (die-forming as opposed to plate inflation, and galvanized cover). This will exactly match the plates purchased (from Teckmark) by the U.S. Corps of Engineers - Cold Region Research and Engineering Lab (CRREL) and recommended by Dr. Vincent Janoo of the CRREL.

Some complications resulted from switching to a dual system instead of the lower U-tubes alone. For instance, it was necessary to install a second set of supply and return pipes, distribution/collector headers, pumps (Bell & Gossett, Series 80), air separators (AMTROL Model 2-1/2-AS-L), expansion tanks (AMTROL Model AX-80), and ball valves so that the lower and upper system could be operated independently. This permits testing the sample with the top and bottom both cooled or both heated, or with the top heated and bottom cooled, or with the top cooled and bottom heated. However when cooling and heating are required at the same time, both the chiller and boiler will have to be run simultaneously. Consequently and because of codes and regulations, the boiler can not be operating in the same room when the cooling equipment is running. A concrete apron was therefore cast and a metal shed was constructed outside the mechanical room for the boiler, and the boiler was moved to the shed. Some additional difficulties resulted from these changes. For instance, part of the west exterior wall of the mechanical room had to be removed and later re-installed because the boiler was too large to go through the room door.

Another capability that was recommended was that, for surface heating, the usage of additional heat lamps (infrared heater) will probably be the most effective way to warm the specimen surface by radiation and therefore best simulating field conditions. This option was investigated during this phase of the project but was funded in a subsequent contract between KDOT and KSU. The final report of this other contract will be prepared separately in the near future.

It is estimated that, using the designed system, the time necessary to bring the environmental pit and slab to the maximum low temperature of -23°C (-10°F) will be between one and two days. Water level is controlled in all test pits that are insulated with a water proof membrane. In addition, the environmental pit is also thermally insulated from the inside as shown in Figure 11.

Thermocouples have been obtained and installed on the tubes and also for usage under the subbase and below the pavement. A data acquisition (DAQ) system was acquired from National Instruments Corp. including several SCXI modules on a mounting chassis and a data acquisition computer board. The software LabView was also purchased and installed to collect and analyze the data.

3.4 Water Table and Soil Moisture Control

To obtain controllable soil moisture content, a sprinkler/drainage system was installed in both the middle pit and the environmental pit. The inside wall of the concrete pit were coated with a water proof sealant to prevent leakage of water into the concrete and corrosion of the reinforcing bars. For the environmental pit, a water tight rubber membrane was used to cover the inside wall of the pit, on top of the thermal insulation to prevent water from getting into the wood and styrofoam used.

3.4.1 Water Sprinkler/Drainage System

The water drainage system was placed before the pits were filled with soil. The water sprinklers were installed in the large pit after the subgrade soil and the aggregate base were placed and compacted. The water sprinkler consists of three soaker hoses buried right under the surface of the aggregate base, transverse to the direction of wheel rolling, and under the concrete pavement. The location of the hoses is at 0.6 m (2 ft), 3.1 m (10 ft) i.e. at the middle, and 5.5 m (18 ft) spacing from one end or the other of the pit. The middle soaker hose was used alone during the concrete pavement test (it lays well under the PCCP joint) to achieve the most serious soil erosion and pumping action under the joint.

Three water collectors were placed horizontally at the bottom of each of the pits, two along two sidewalls and the third diagonally across the pits. The collectors consist of 102 mm (4 in.)

perforated black plastic pipes (corrugated) leading into a metal riser tube of 254 mm (10 in.) diameter installed vertically at one corner of each pit. A layer consisting of 279 mm (11 in.) of UD-1 or pea gravel was laid at the bottom of both pits to facilitate water collection and drainage. A layer of filter fabric was then placed on top of the gravel before the soil was placed.

The riser tubes have a large side opening at the bottom to allow for the collector pipes to drain in. The advantage of using the riser tubes is that the water level can be observed from the surface and excess water can be removed by dropping a sump pump to the bottom when necessary.

3.4.2 Soil Moisture Sensors

TDR (Time Domain Reflectometry) and Neutron probes are the most popular methods for in situ soil-moisture measurements. However, the need for permanent access holes through pavements down to subgrades as well as the frequency with which these holes would have to be exposed for taking moisture measurements, made the Neutron probe a secondary choice. TDR was found to be more convenient for pavements as the waveguides could be buried under the test pavements and intermittent readings of soil-moisture can be taken without disturbing the testing activity. In the 6.1 m×6.1 m (20'×20') pit three waveguides (three-rod type manufactured by SoilMoisture Equipment Corp.) were installed under the pavements in the subbase along the centerline of the pit (aligned parallel to the rolling wheels) at 1.2 m (4 ft), 3.1 m (10 ft) i.e. at the middle, and 4.9 m (16 ft) spacing from one end or the other. At each location, the waveguide was installed into the subgrade by making a 102 mm (4 in.)-diameter, 76 mm (3 in.)-deep hole, and drilling three 6 mm (1/4 in.) holes with a steel rod for the sensor probes. The top of the waveguides was covered by about 13 mm (½ in.) of soil and so were the coaxial cables that were buried and extended to the sides of the pit. Cable connections were sealed with silicone-type joint sealant. At the sides of the pavement section, each cable was passed through a small vertical pipe to protect it from damage during specimen casting and removal.

TDR were used to measure the soil moisture at the beginning of testing and at regular interval as water was being added to the subgrade. Moisture measurements were made with a Tektronix Model 1502 TDR cable tester. The calibration of the TDR waveguides, and correlation of results with dry density (γ_d) of soil and amount of water added to the soil were done according to a procedure developed and used in other research at KSU [Hossain ,1996]. Results are summarized in [Melhem *et al.*, 1998].

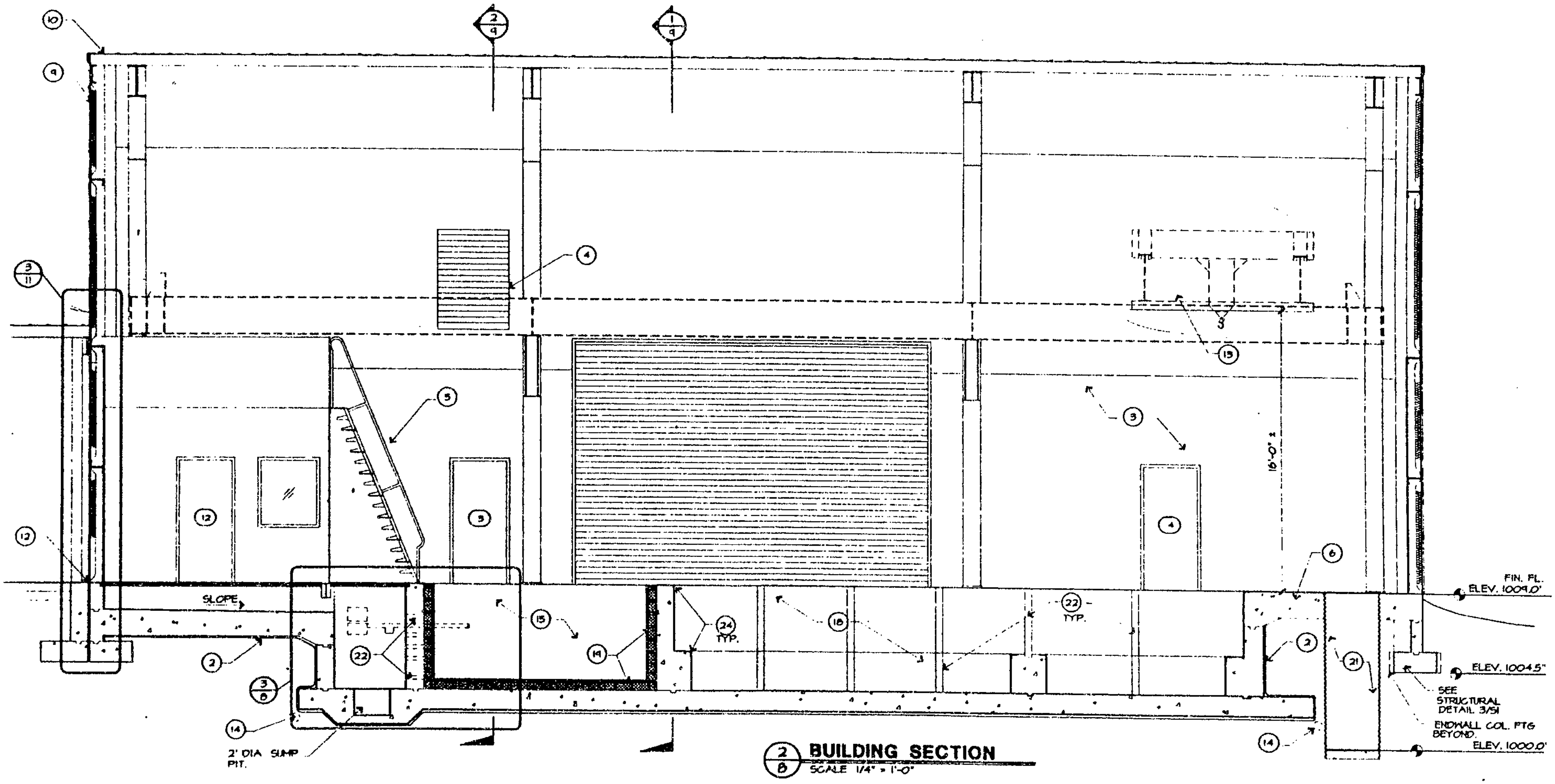

Figure 8. Longitudinal Cross-section in the Building
(Drawing provided by KSU Division of Facilities)

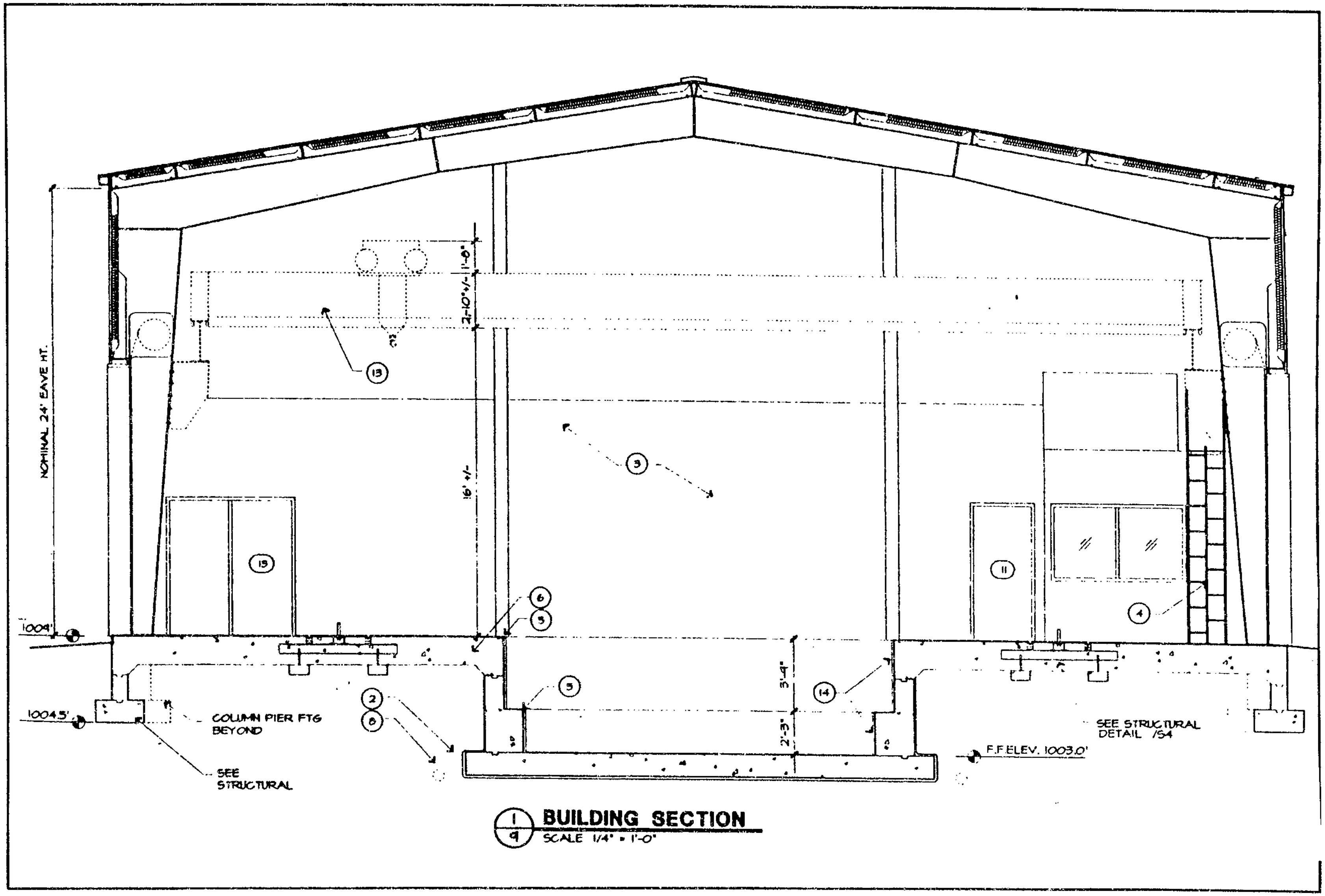

Figure 9. Transverse Section through the Main Test Pit
(Drawing provided by KSU Division of Facilities)

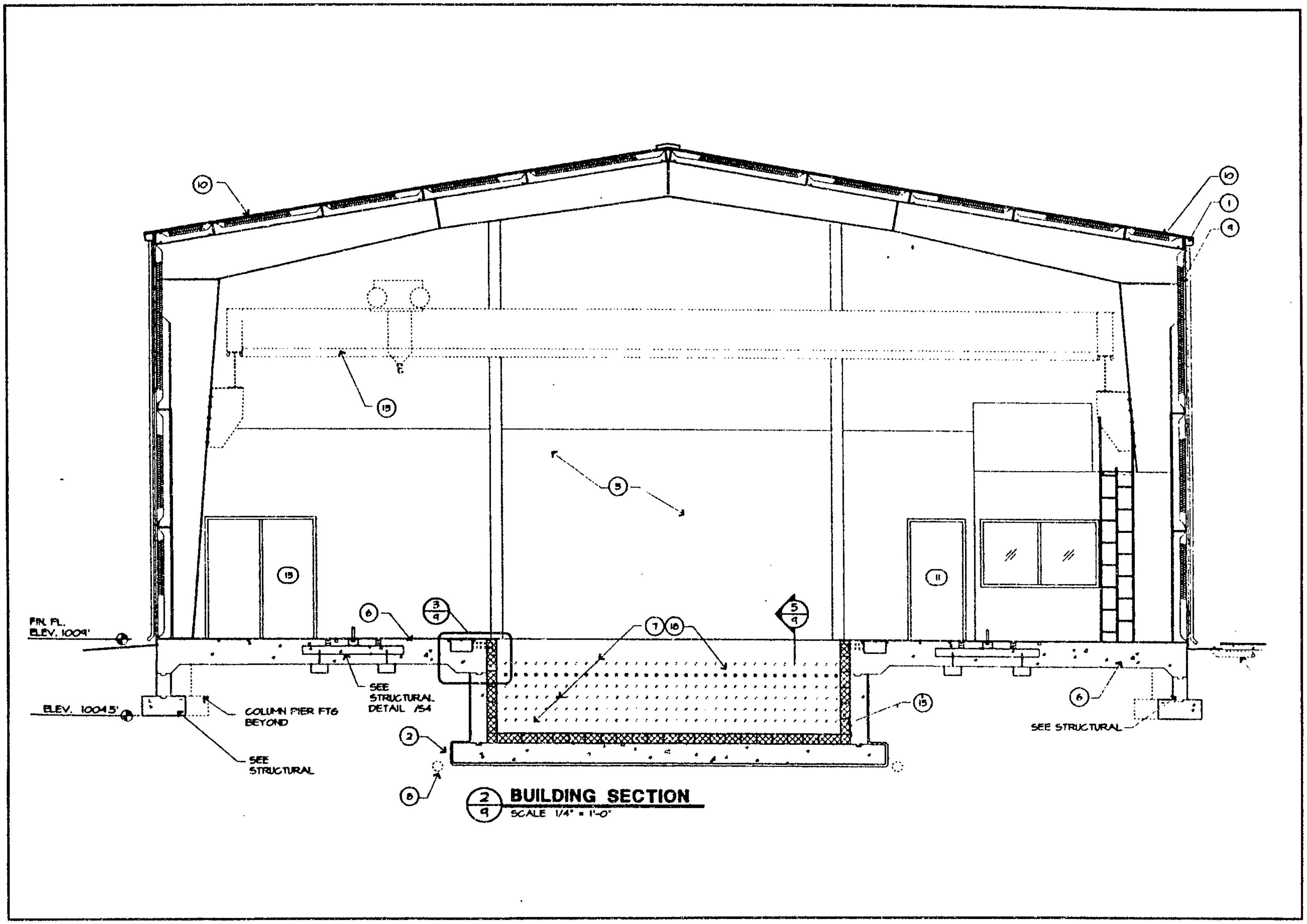

Figure 10. Transverse Section through the Environmental Pit
(Drawing provided by KSU Division of Facilities)

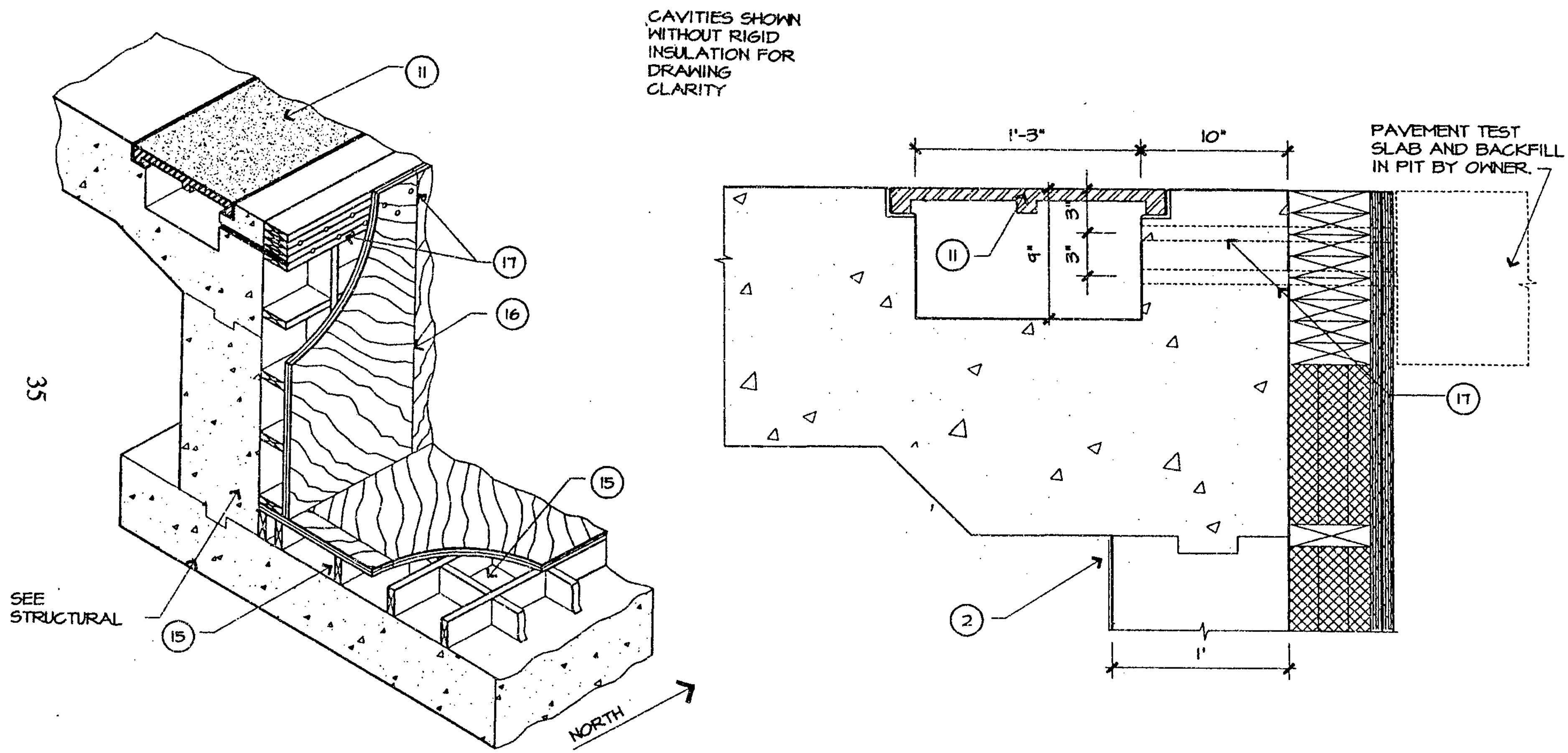

Figure 11. Environmental Pit Insulation and Slab Attachment Details
(Drawing provided by KSU Division of Facilities)

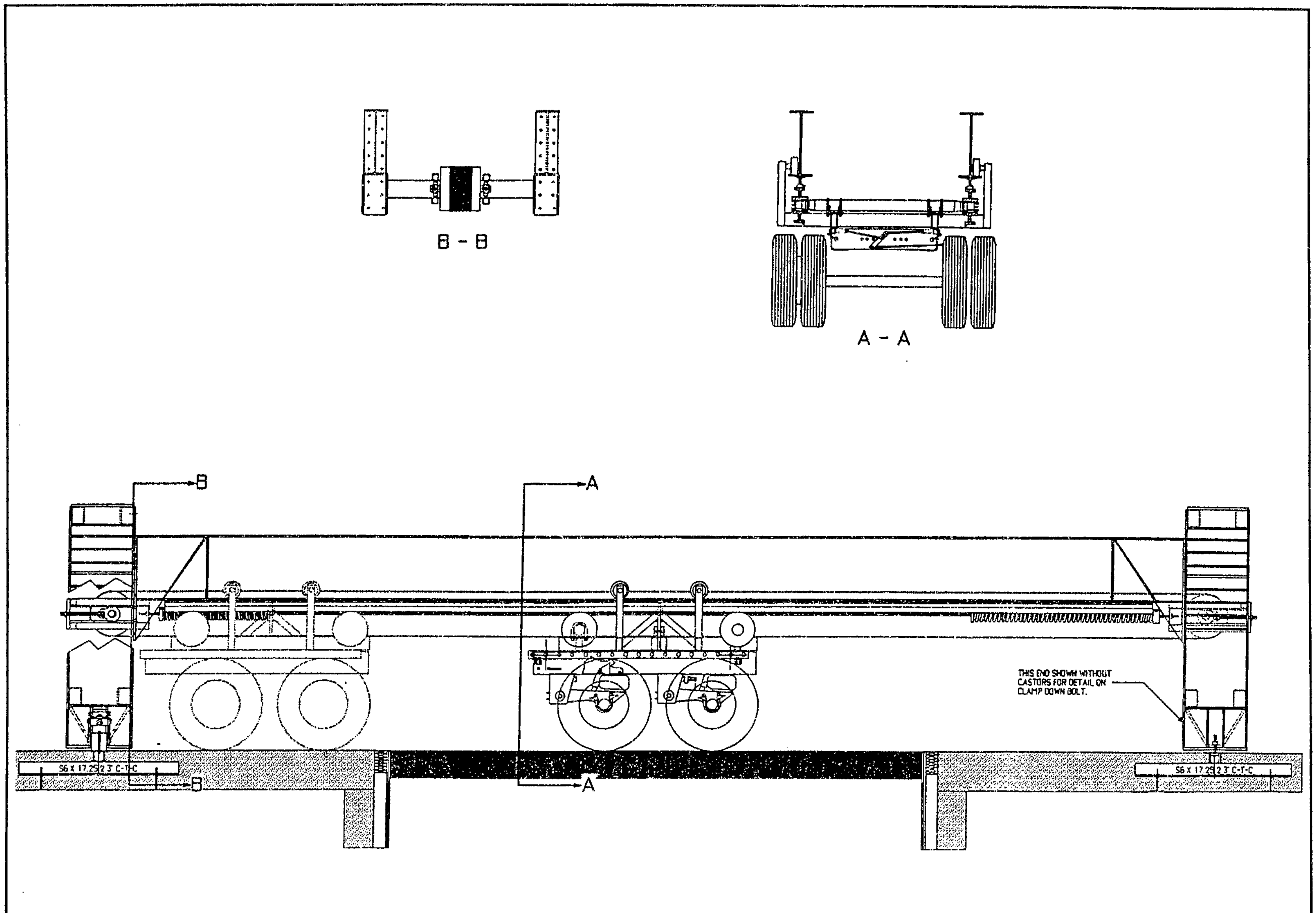

Figure 12. Accelerated Testing Loading Machine
(Drawing provided by Cardwell Concrete Systems)

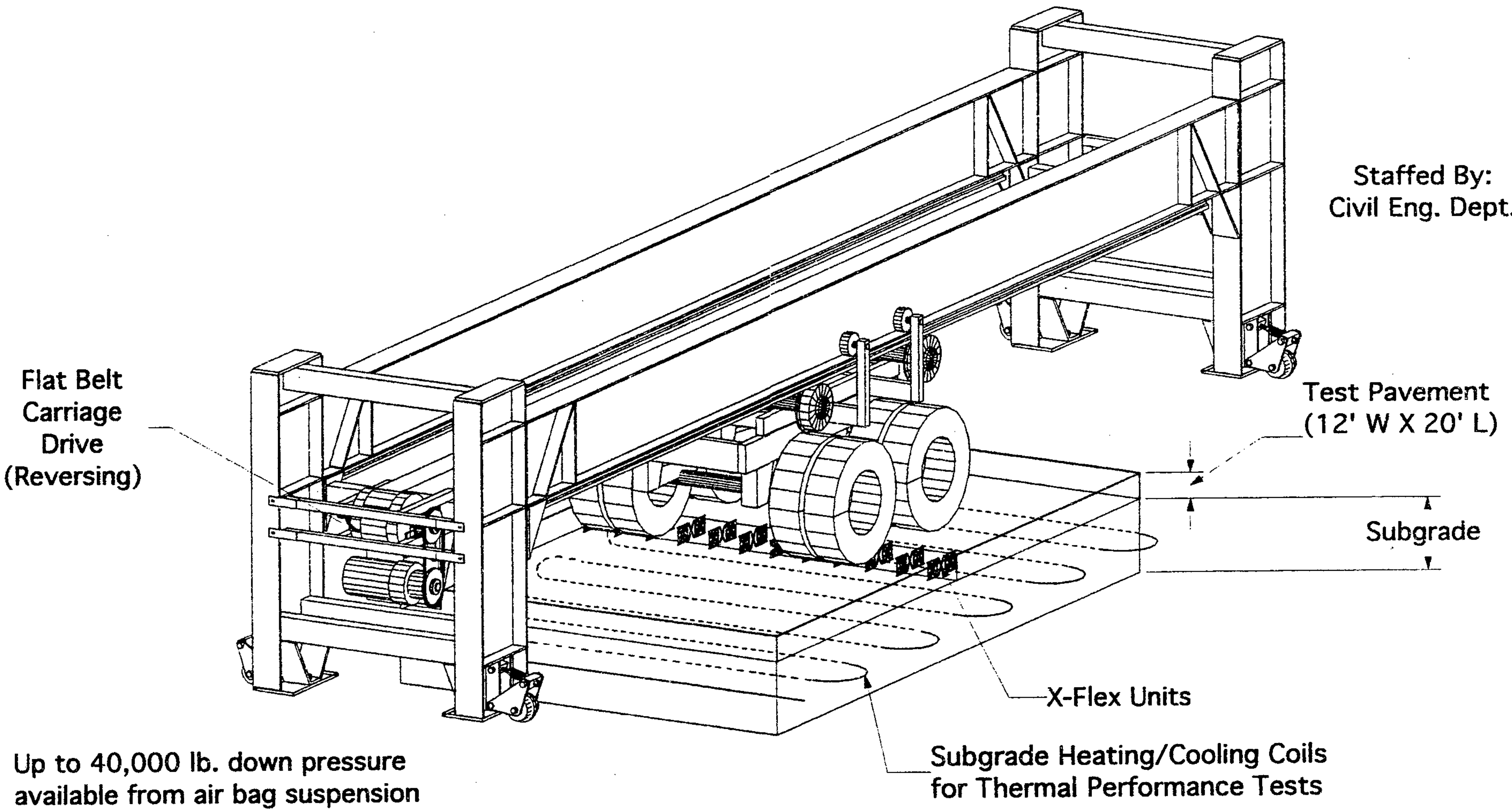

Figure 13. 3-D View of the Testing Machine
(Drawing provided by Cardwell Concrete Systems)

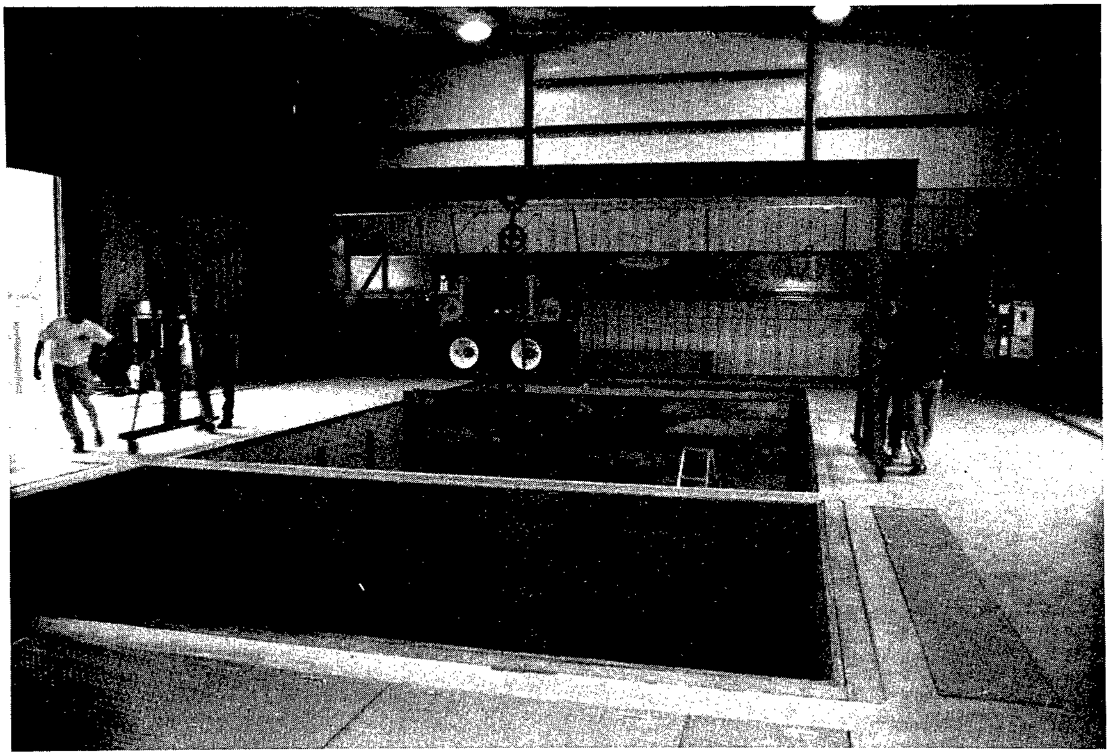

Figure 14. General View of the Lab Space before Filling the Pits.

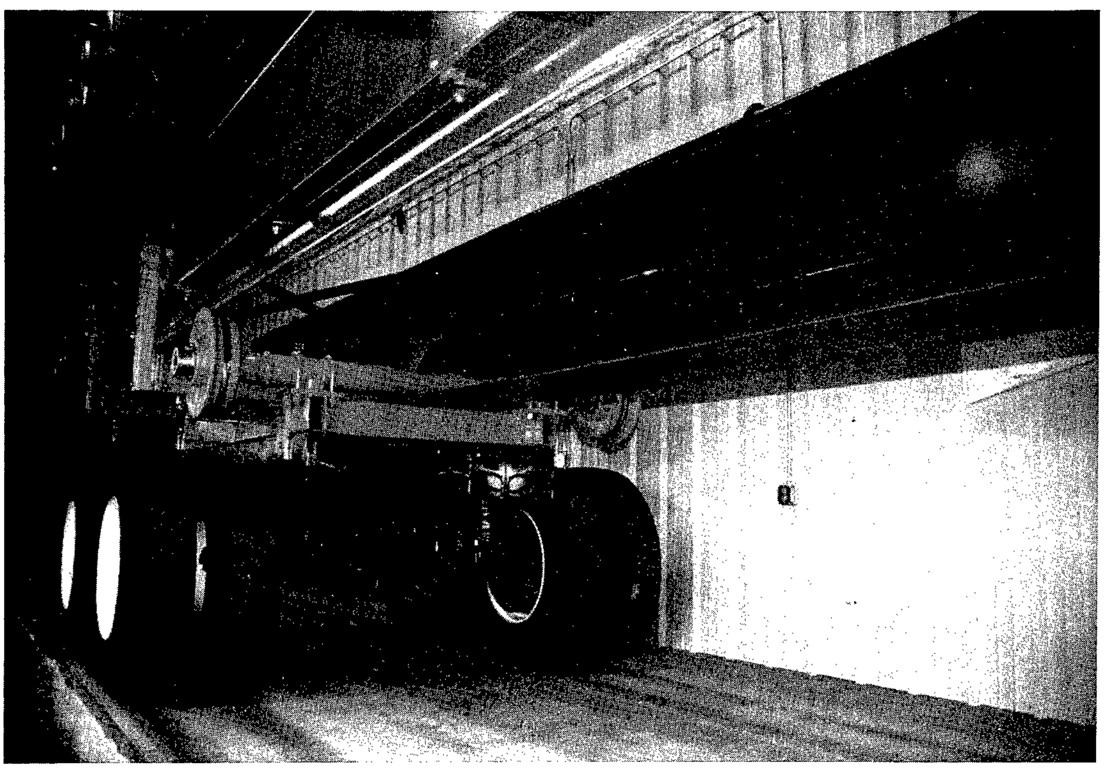

Figure 15. Bogie Driving Belt and Air Springs

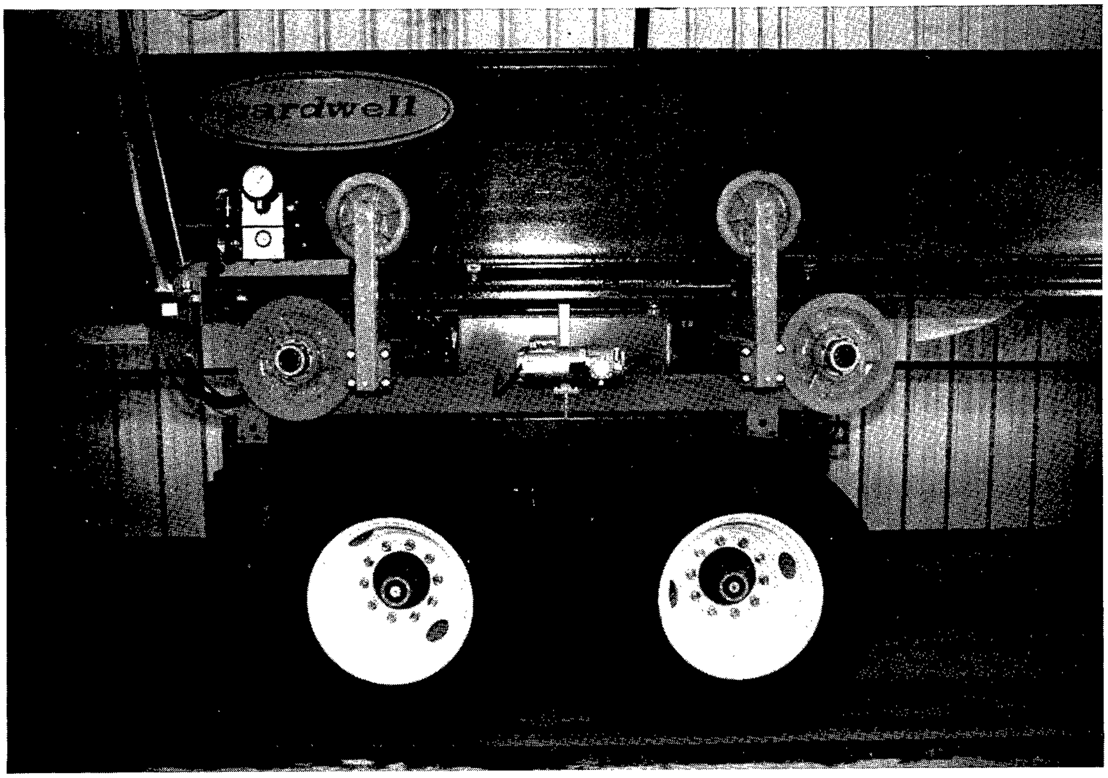

Figure 16. Front View of the Wheel Assembly (Bogie)

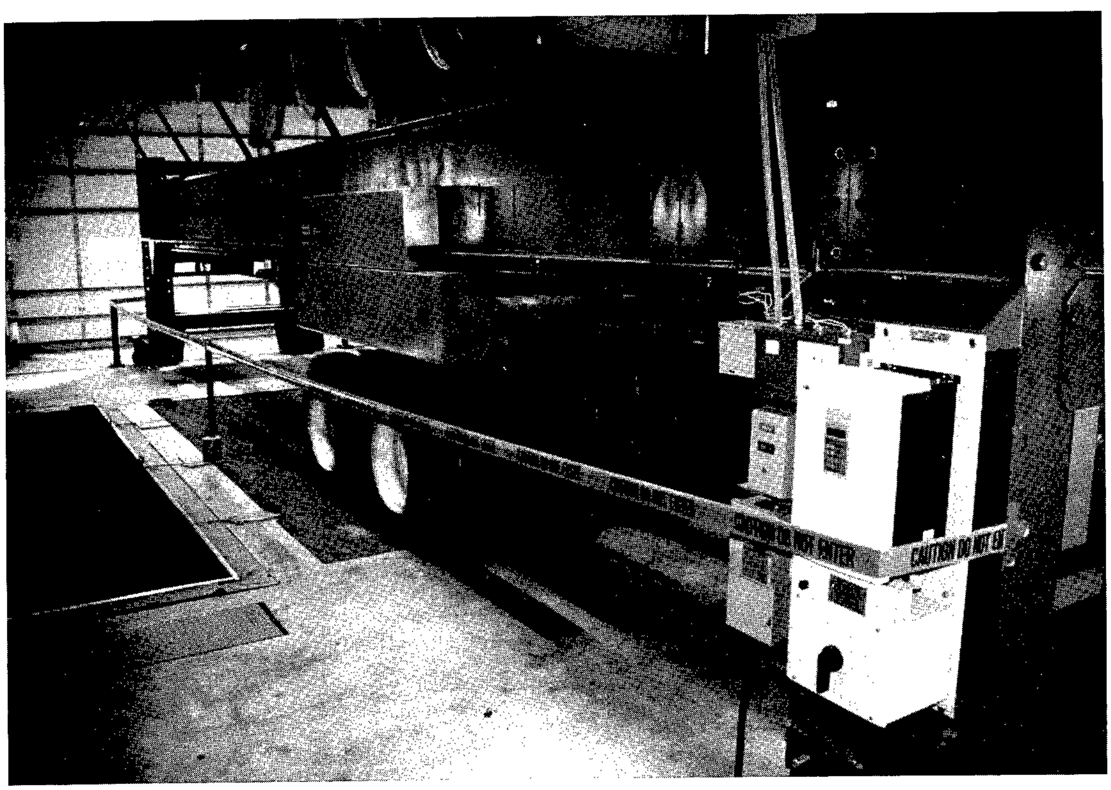

Figure 17 Picture of the Machine During Testing
(Photo taken by KSU Photographic Services)

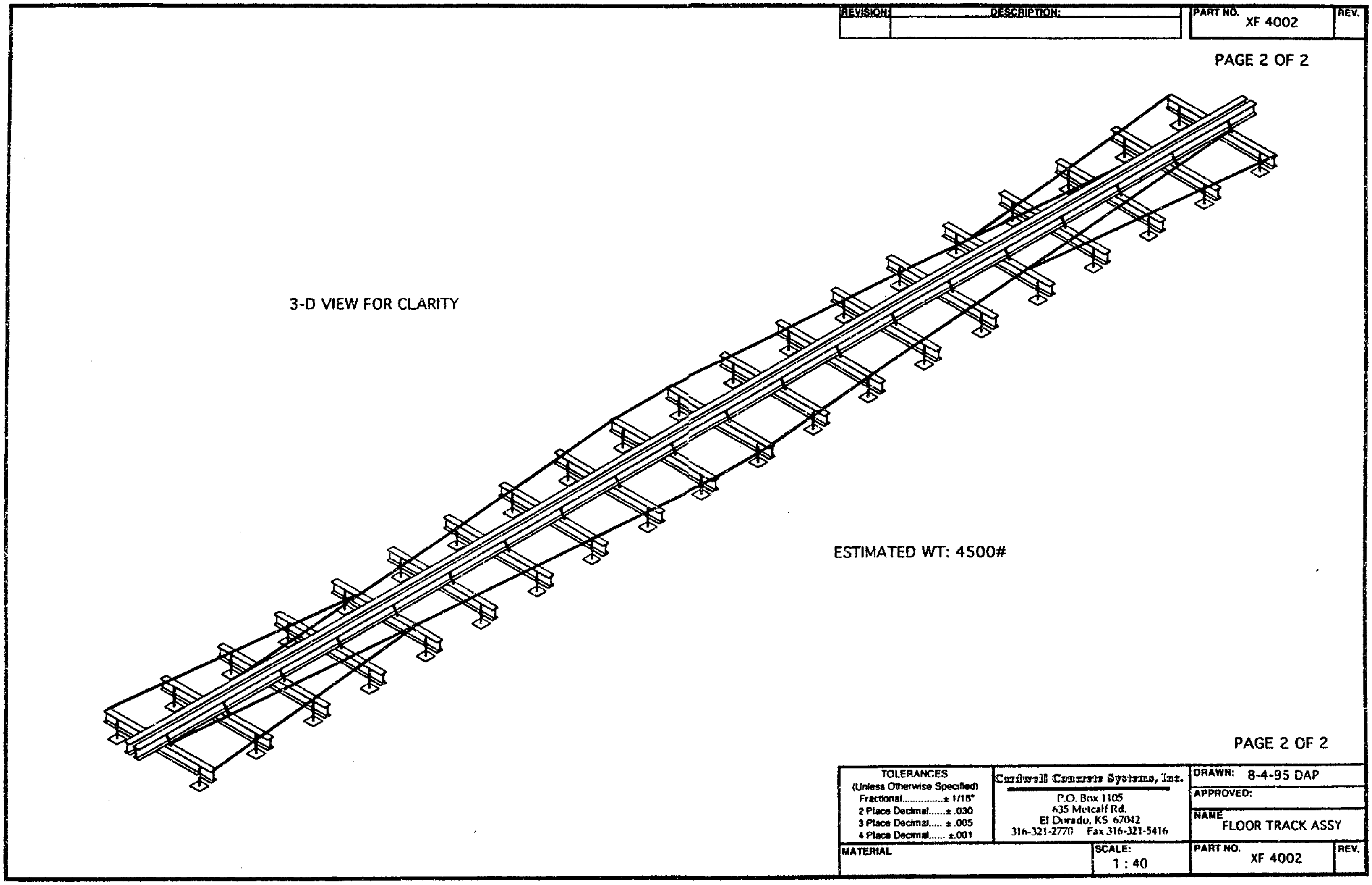

Figure 18. Isometric View of the Apparatus Floor Track
(Drawing provided by Cardwell Concrete Systems)

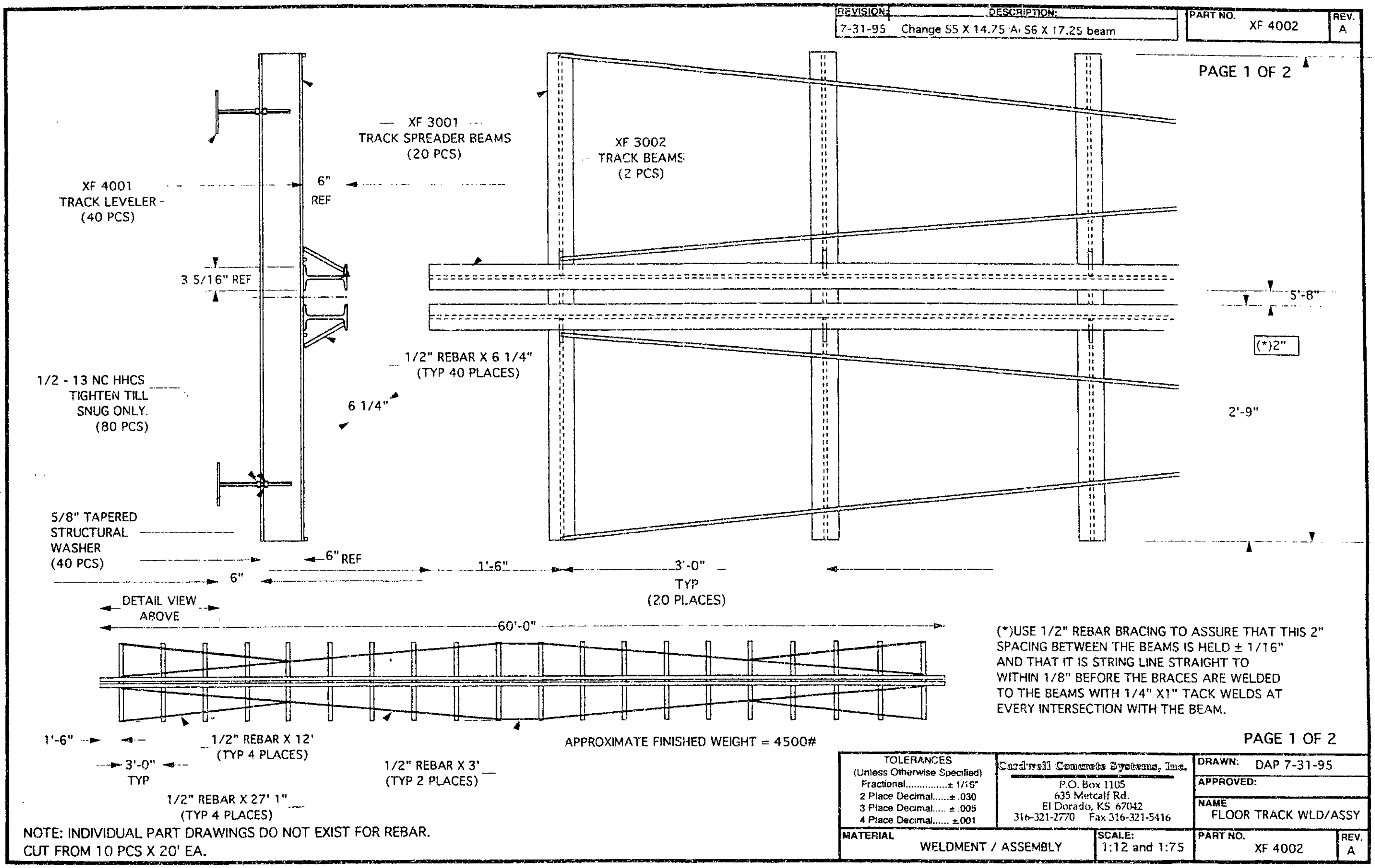

Figure 19. Details of the Apparatus Floor Tracks
(Drawing provided by Cardwell Concrete Systems)

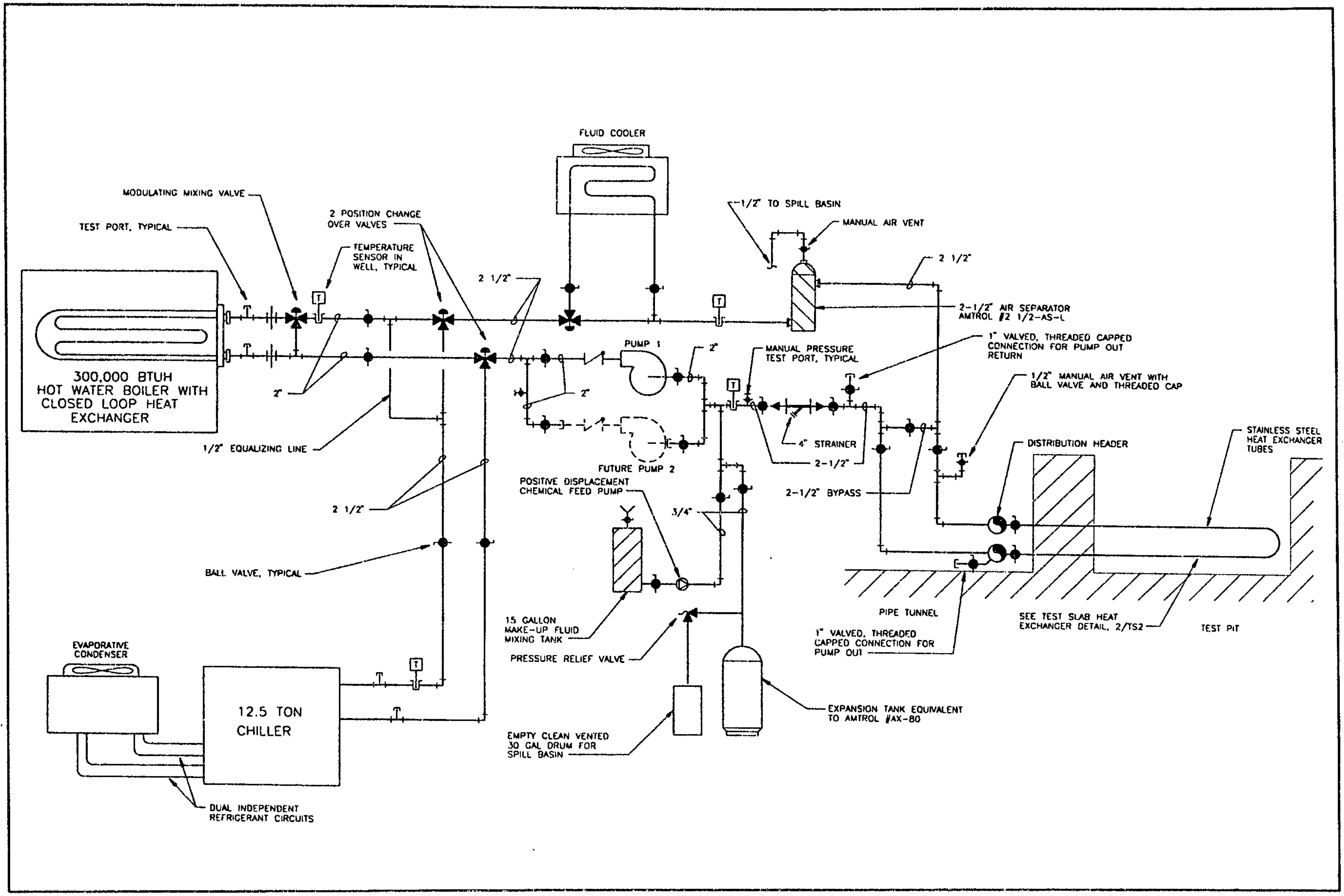

Figure 20. Test Heating/Cooling System Flow Diagram
(Drawing provided by Orazem & Scalora Eng'g,)

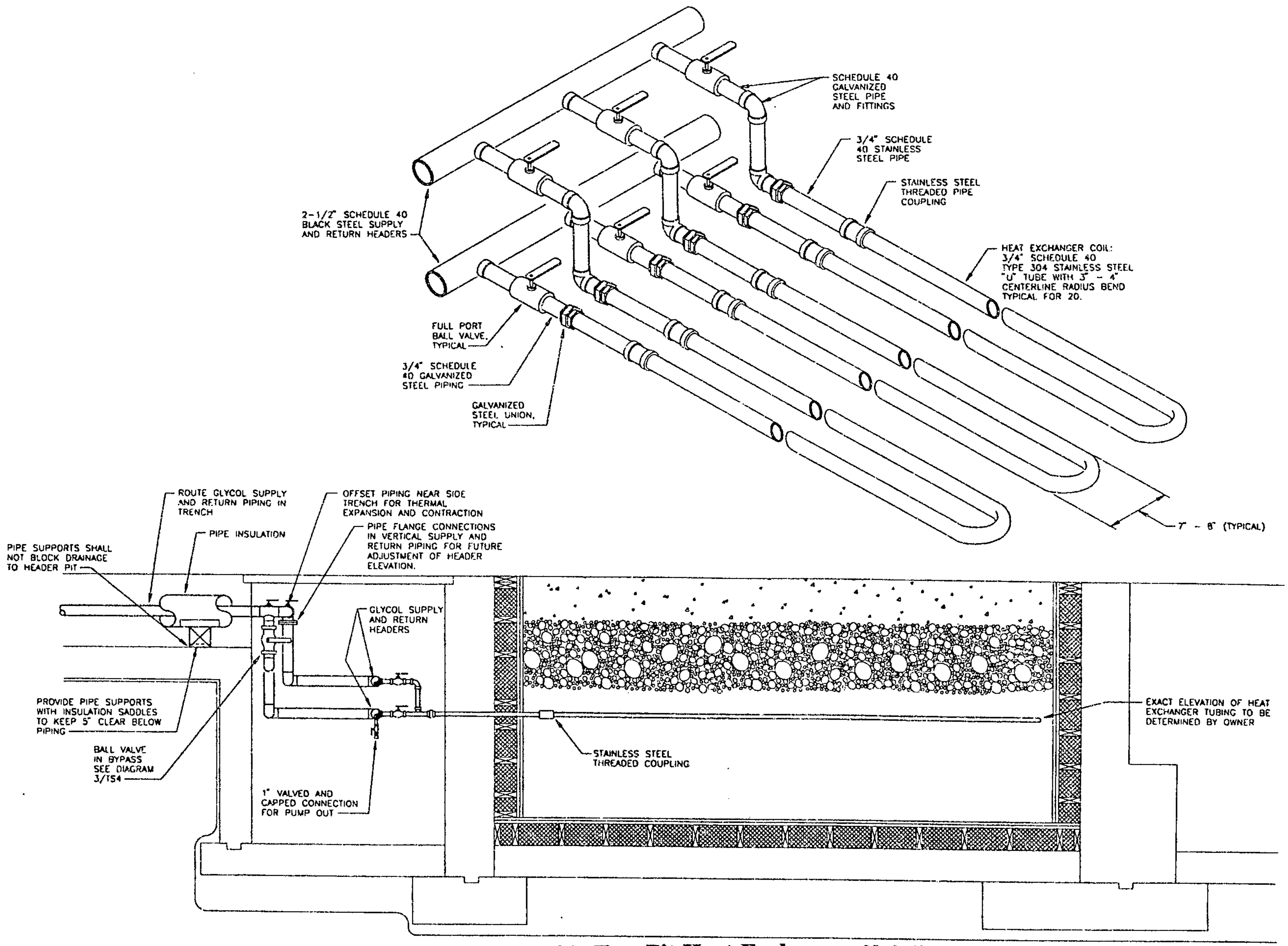

Figure 21. Test Pit Heat Exchanger Detail
(Drawing provided by Orazem & Scalora Eng'g)

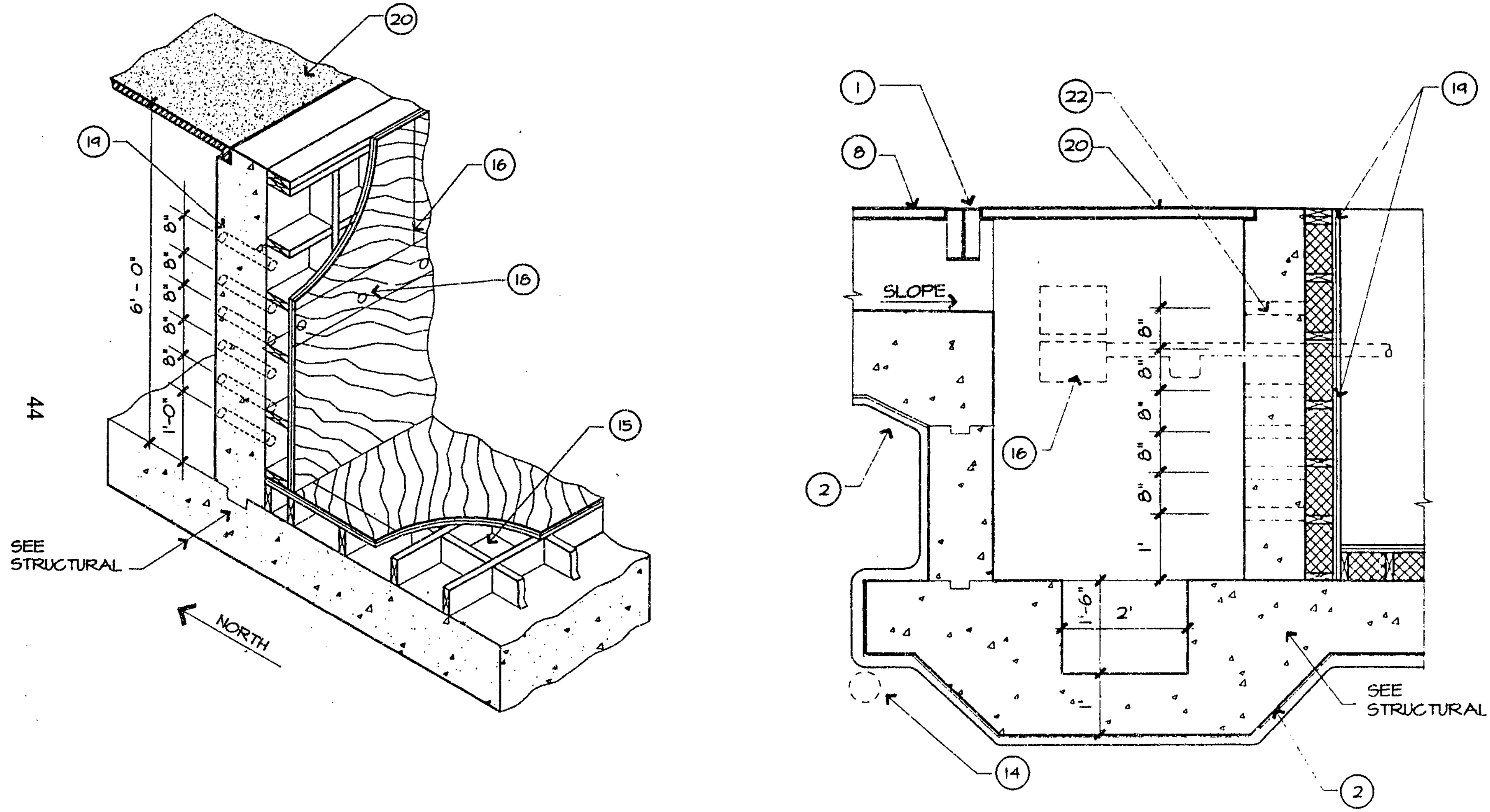

Figure 22. Provisions for Variable Heat Exchanger Elevation
(Drawing provided by KSU Division of Facilities)

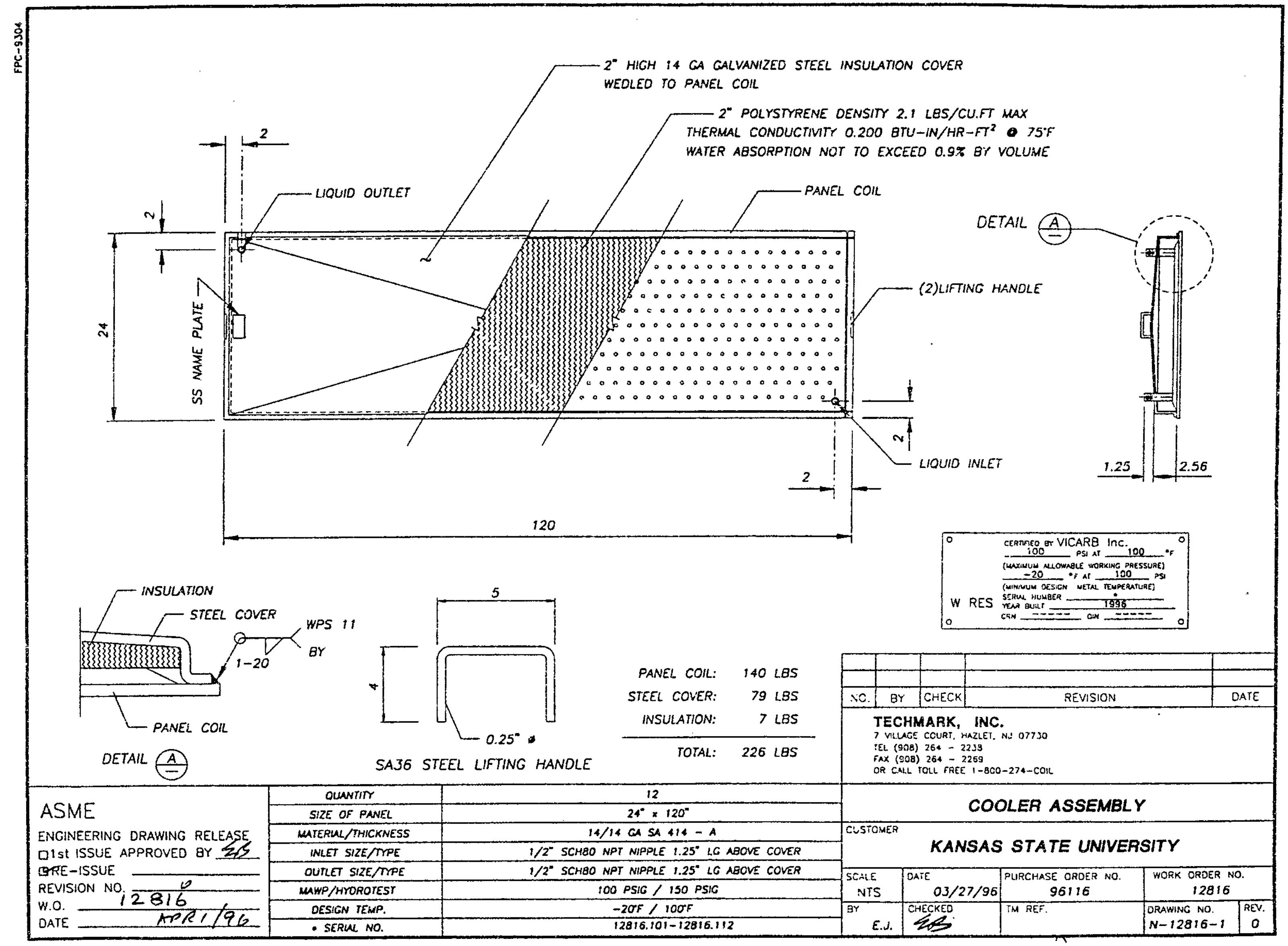

Figure 23. Details of the Thermal Plate Coils
(Drawing provided by Techmark, Inc.)

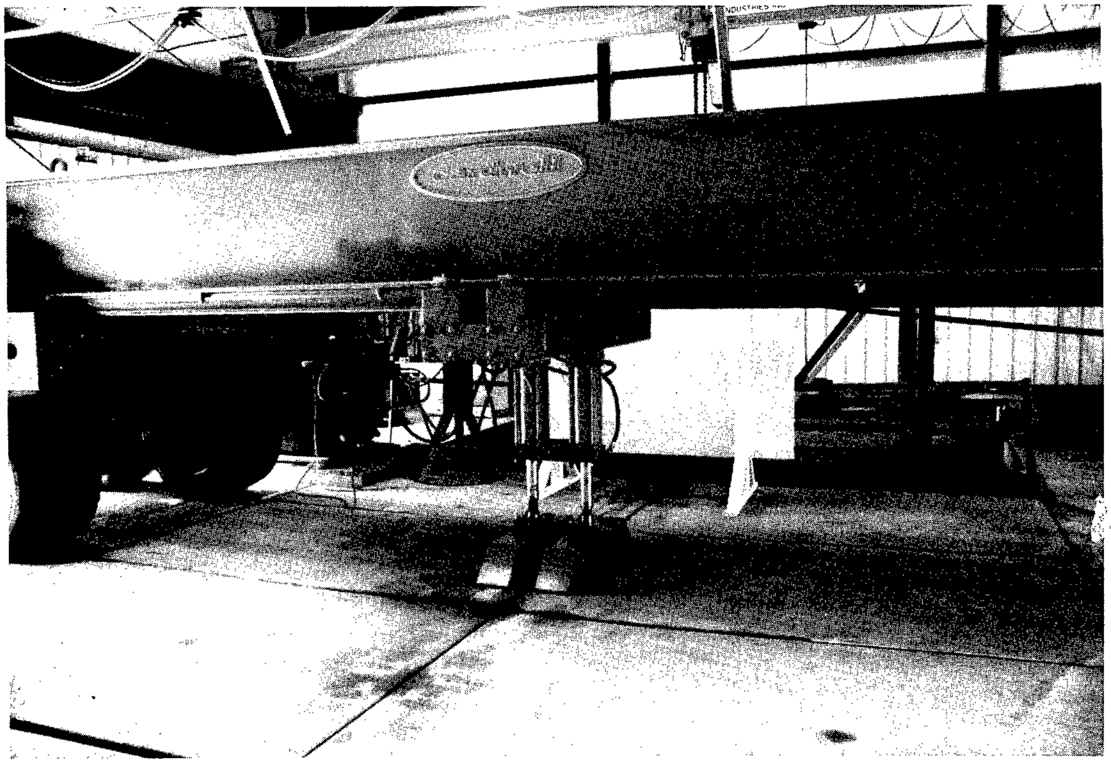

Figure 24. Testing of the Three PCCP Joints

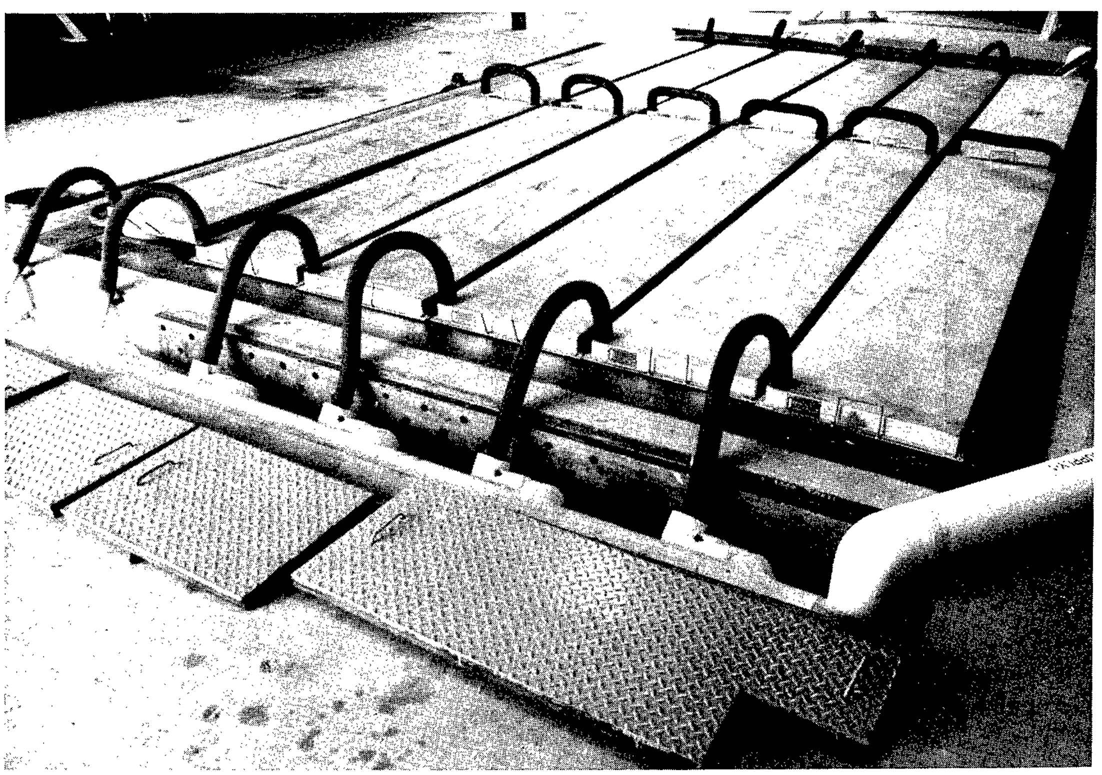

Figure 25. Surface Coils and Distribution Headers

4. TESTING ACTIVITY

During the time period between January 1997 and the end of August 1997, two experiments were conducted in the K-ATL. These experiments are presented in this chapter. They are first summarized below and discussed in more detail in subsequent sections (Section 4.2 and 4.3).

The first experiment is the so-called shakedown test, which consisted of 76 mm (3 in.) of asphalt overlay over a 102 mm (4 in.) cold in-place recycled (CIPR) base stabilized with fly ash. This test resulted in the application of 168,000 load repetitions using the wheel carriage (tandem axle with dual wheels) loaded to 142 kN (34,000 lbs) and tire pressure of 620 kPa (90 psi). The operation of the testing machine started on January 10, 1997 with the first load, and the last cycle was applied on March 29, 1997. This time period included many interruptions to debug the system, perform repairs and modifications to the machine, and conduct Falling Weight Deflectometer tests on the specimens.

The second experiment is the testing of the PCCP joints long awaited for and actually the main initial incentive to build a laboratory at KSU. Using the same subgrade and aggregate base, three sections of a 229 mm (9 in.) pavement were placed in the same middle pit. The test lasted from May 15, 1997 till August 25, 1997. The pulse loading assembly (thumper) was used to pound the different types of PCCP joints, and a total of 4.7 million load repetitions were applied during this time period. Here again, many interruptions had to take place to perform repairs on the machine, modify the electronic control, and conduct FWD tests on the specimens.

In general these two experiments were most useful to identify the kinds of problems that can arise during the two different types of testing (rolling and thumping), and categorize the necessary repairs and their respective efficiency and downtime. They also helped ascertain the actual physical capabilities as well as limitations of the testing equipment. This was an important step to achieve readiness before embarking into any major testing program.

4.1 Soil Compaction and Test Preparation

4.1.1 Test Preparation

Due to the delay in the building construction, and the additional delay in getting the thermal equipment to operate as desired, it was not feasible to conduct the first pavement tests in the environmental (North) pit. On the other hand, the south pit was dedicated for a separate test pertaining to earthquake research. It was therefore decided to performed the first pavement experiments in the central pit of the lab, which is a square 6.1 m×6.1 m (20'×20') of 1.8 m (6 ft) depth. Therefore a retaining wall between the central pit and the south pit was designed and constructed. This wall needed to be very strong and stiff to avoid earth movement under the wheel loads of the testing machine. It is resting on the 0.6 m (2 ft)-wide and 0.69 m (2.25 in.) high existing pedestal so that the total clear width of pavement test specimens placed at one time will always need to be less than or equal to 5.8 m (19 ft). Any pavement section or set of adjacent sections will then be 6.1 m (20 ft)-long and 5.8 m (19 ft) or less wide. The wall was made of 6.1 m (20 ft)-long steel I-beams vertically stacked sideways such that the beams flanges constitute the internal and external faces of the wall. The internal face of the wall was covered with the same waterproof rubber membrane used in the environmental pit.

In the middle pit, on top of the 279 mm (11 in.) of pea gravel and the filter fabric layer, 1220 mm (48 in.) of subgrade soil were placed and compacted. The same subgrade was put in the environmental pit. The environmental pit depth-profile is as follows (from bottom up): The bottom (and four sides) of the pit has an 203 mm (8 in.)-thick wood frame enclosing styrofoam thermal insulation. Then come the 279 mm (11 in.) of pea gravel (covered by the filter fabric). On top of the gravel, 356 mm (14 in.) of the same soil used in the other pit were placed and compacted. Then 76 mm (3 in.)-thick Glassfoam panels (from Corning) were placed side by side and covered with black tar, as recommended by the manufacturer, for additional thermal insulation. On top of the panels, about one inch of sand (on average) was placed to level the surface so that the stainless-steel U-tubes could be laid. The U-tubes are at 914 mm (36 in.) from the top of the pit or lab floor level. At the time of this report preparation, about 610 mm (24 in.) of subgrade soil have been placed and compacted above the U-tubes.

4.1.2 Subgrade Compaction

The subgrade used consists of a typical silty soil (AASHTO A-4) from a borrow pit recently used on a number of road construction projects around Manhattan, Kansas. The soil (Fleming Pit) has a liquid limit of 28% and a plasticity index of 9%. Approximately 84% of the soil passes No. 200 sieve. The Standard Proctor test showed a maximum dry density (MDD) of 1826 kg/m^3 (114 pcf.) with 14% optimum moisture content (OMC). The soil was placed in the pit in approximately 152 mm (6 in.) lifts and compacted to 90% of the laboratory MDD with a baby sheep-foot roller. The density obtained was monitored with a nuclear gage. The top 457 mm (18 in.) of the subgrade were compacted to 95% of MDD. The subgrade was instrumented with three Time Domain Reflectometry (TDR) waveguides for monitoring moisture contents. The in-place moisture contents of the subgrade was approximately 15.5% during construction and decreased to about 10.5% three months later.

4.1.3 Subbase Placement

The granular subbase was mostly 19 mm (3/4 in.) maximum nominal size crushed limestone with approximately 15% passing No. 200 sieve. This material was placed in loose lift thickness of 152 mm (6 in.) and compacted to 95% of the MDD of 2323 kg/m^3 (145 pcf.). The optimum moisture content of this aggregate base (AB-3) material was approximately 10%.

4.2 Shakedown Test

4.2.1 Test Section Construction

The shakedown test was designed to check the wheel load carriage and driving mechanism. The specimen was an asphalt overlay over a layer of cold in-place recycled (CIPR) asphalt pavement. In addition to checking the equipment, the purpose of the experiment was to validate the performance of the CIPR. A 3.7 m (12 ft)-wide by 6.1 m (20 ft)-long test section consisted of 76 mm (3 in.) of asphalt overlay (KDOT mixture BM-2C) over a 102 mm (4 in.) CIPR-fly ash base. This was placed on top of the 152 mm (6 in.) aggregate subbase (KDOT AB-3), 1220 mm (48 in.) of soil subgrade, and 279 mm (11 in.) pea gravel drainage layer. The bottom and sides of the pit were made out of 305 mm (12 in.)-thick concrete, or 610 mm (24 in.) in some places such as the lower parts of the wall, and painted with sealant to insure water tightness.

The CIPR layer was constructed with the reclaimed asphalt pavement (RAP) materials of 19 mm (3/4 in.) maximum nominal size milled out of an existing roadway. The RAP materials was placed in a layer of the required thickness and 10% class C fly ash (by weight) was spread uniformly on the RAP. The water was added to the materials with a hose to produce a consistency so that the materials could be worked (mixed) with a roto-tiller. The compaction was done by a steel-wheeled baby BOMAG roller.

The 76 mm (3 in.) asphalt overlay consisted of dense-graded, 19 mm (3/4 in.) maximum nominal size aggregate gradation. The individual and combined gradations of the aggregates were evaluated. The mixture consisted of 70% CS-1 (crushed limestone), 6% CS-2 (limestone screening), 6% SSG-1 (concrete river sand) and 18% SSG-2 (fine river sand). The optimum asphalt content found in the Marshall mix design was 5.75% with the binder grade AC-10. The mix had a Marshall stability of 14,676 kPa (2,130 lbs), air voids of 4.9%, VMA of 12.1% and bulk density of 2347 kg/m^3 (146.5 pcf.) at the optimum asphalt content. This mixture is used as a binder course on heavily traveled asphalt pavements in Kansas.

The BM-2C overlay was placed in mid-December 1996 with a Blaw-Knox paver using mixture from a local drum-mix plant. At that time, the plant was producing mix for paving an urban arterial pavement in Manhattan. Considerable difficulties were faced during placement near the ledge of the pit. Also, heat loss from the mixture was a big concern. Due to lack of much sand in BM-2C, the mixture tended to lose heat earlier than expected. However, rolling was started immediately with a steel-wheeled roller and that resulted in respectable densities in most of the overlay. However, some density (AASHTO T 166; Procedure A) values were low as indicated by the properties of the three cores taken in between the wheel paths immediately after construction as shown below. The computed in-place air voids ranged from 7.9% to 10.6%.

Core No.	Bulk Density (pcf.)	Resilient Modulus (ksi.)
1	136.8	323
2	132.7	-
3	133.8	49

Resilient modulus tests were conducted on 64-mm thick core samples from each test section following ASTM D 4123 test procedure. Tests were run at 20° C using a pulse load of 0.1 sec duration and 0.9 sec rest period. Indirect tensile loads applied varied from 580 N to 5,560 N to obtain measurable deflections in the range of 100 μm to 200 μm. No measurement could be made on Core #2 since it would not show resilient deformation under the load, apparently due to its lower density.

4.2.2 Loading and Data Collection

Deflection data were collected on the section at five different locations on each wheel path with a Dynatest 8000 FWD at 4 m (13 ft) intervals, approximately one week after construction before any loading was applied. The first sensor was located at the center of the loading plate with six others at a uniform radial distance of 25 mm (1 in.) apart. Three drops of the FWD load were used for target loadings of 31 (7), 40 (9) and 67 kN (15 kips). The deflection data obtained were very high and when processed with MODULUS, the resulting modulus of the CIPR layer was found to be very low. This layer was assigned a layer coefficient of 0.08, and other layer coefficients were assumed as: BM-2C = 0.34 and AB-3 = 0.15. With an assumed mi. = 1.0, the resulting structural number was 2.24. This structural number was used in DARwin to estimate the number of 80 kN (18 kip) ESAL's needed to reach a terminal serviceability of 2.5 from an initial serviceability of 4.2. The reliability value was chosen was 50% with an overall standard deviation of 0.45. The number of ESAL's to be carried by this section at the terminal serviceability of 2.5 was found to be 64,636, which translated to approximately 60,000 repetitions of 151 kN (34-kip) K-ATL tandem axle load.

A monitoring plan was developed to measure the extent of cracking, rutting, deflection and roughness at 4,000, 10,000, 20,000, 30,000, 40,000, 50000 and 60,000 repetitions of the K-ATL axle loads. As mentioned before, base-level deflection data with an FWD were also collected before loading. The transverse profiles at three different locations on the test section and the longitudinal profile on each wheel path were also measured. Both profiles were measured with a Face Dipstick, and efforts to measure longitudinal profiles with a South-Dakota profilometer were largely unsuccessful.

Loads were applied continuously during work hours on week days except when the machine was stopped for maintenance and modification. Severe rutting (up to one inch) was observed after 30,000 repetitions of the K-ATL wheel loading (Figure 26). The ruts were repaired with hot mix asphalt (SM-2C and SM-1T). Loading continued up to 145,000 repetitions (Figure 27). Then a new thin patching material was placed (STIX, by a company in Kansas City) at the beginning and end on both load paths where the wheels enter and leave the specimen. At 168,000 load repetitions, the maximum rut depth had again reached 1 in. and the patch had cracked. The section was then removed although no cracking was visible in the pavement.

The load path (and testing machine) was moved 102 mm (4 in.) to the South, then 102 mm (4 in.) to the North, then back to its original track every 20,000 load applications. The FWD tests were performed at several intervals during the experiment (Figure 28). The dates and number of load applications of each test were as shown below:

No. of Load Rep.	Date	
10,000	1/24/97	
20,000	1/30/97	
30,000	2/4/97	(before repair)
30,000	2/14/97	(after repair)
40,000	2/19/97	
60,000	2/28/97	
145,000	3/25/97	

Detailed data from this experiment were analyzed and results are summarized in [Melhem *et al.*, 1998]. This includes mechanistic response analysis of the deflection data, back-calculated layer moduli, stress-strain states, and transverse profile data. A design sensitivity of the CIPR pavement layer is also included.

4.3 PCCP Tests

Three 6.1 m(20 ft)-long strips (lanes), 229 mm (9 in.)-thick, were constructed side-by-side with a PCCP joint at mid-length. The width of the lanes is such that the footprint of each pair of wheels will always be approximately in the middle of the lane. Since the distance between the centerlines of each pair of wheels on the single axle is normally between 1.8 m (6 ft) and 2 m (6.5 ft), lane widths of about 1905 mm (75 in.) were most appropriate. A resulting 76 mm (3-in.) gap or ditch resulted on the north and south sides of the concrete between the pavement and the side walls. This was done to observe the water level at the aggregate base level, and watch side cracks of the concrete at the joints.

4.3.1 Material Specifications

Mix design, air entrainment and aggregate-type followed KDOT current practice as in the Standard Specifications for State Road and Bridge Construction (referred to as "KDOT Specs"), Division 400. Pavement construction followed guidelines outlined in Division 500 of the KDOT

Specs. The concrete strength specified was 20,670 kPa (3,000 psi) not to exceed 27,560 kPa (4,000 psi) at the recommendation of the Advisory Committee.

In order to be able to finish the concrete surface with regular size screeds, and produce a separation (crack) at the joint, the contractor chose not to cast the three slab section at the same time. Therefore the North and South slabs were poured in one day (April 3, 1997) and the middle slab was poured the next day (April 4, 1997). The concrete slump tests were 114 mm (4.5 in.) for the first day and 108 mm (4.25 in.) for the second day. The batch received the second day gave an initial slump of 25 mm (1 in.) but water was added to the mix on site until a subsequent test gave 108 mm (4.25 in.) which was considered as close as it can get to the previous day.

Three standard cylinders were cast from each batch and properly cured for the 28 day compressive strength tests. The results of the compressive strength tests gave an average of 28,022 kPa (4,067 psi) for the first day concrete and 23,123 kPa (3,356 psi) for the second day. This means that the concrete in the middle slab (the one with the FiberCon shear transfer devices) is of a lower quality than that of the other two slabs (with the steel dowels and *X-FLEX*'s).

4.3.2 Testing Configuration

The North lane has 6 conventional steel dowels 30 mm (1-3/16 in.) diameter, the middle lane has 6 FiberCon dowels, and the South lane has 11 *X-FLEX* units fabricated by Cardwell Concrete Systems (later renamed Concrete Systems, Inc.). All three types of shear transverse devices are 457 mm (18 in.) long. FiberCon is a proprietary product of Concrete System Inc., and consists of hollow cylindrical fiberglass tubes filled with a special high-strength concrete mix.

The recommendations of the Advisory Committee on December 14, 1995 were to initiate a crack in the slab by placing the PCC warm and let it cool naturally during curing or using the cooling system. This necessitates restraining the ends from contraction. Since provisions for restraints were not made except in the environmental pit,--as stated above--, and the cooling system was not yet operational, it was not possible to initiate the crack in this fashion. Instead, for all slabs, a crack was introduced at the joint location right after the concrete was poured and its surface was finished. A folded sheet metal plate was inserted about three inches before the concrete had set, and lifted immediately to form the crack. In addition, for the *X-FLEX* slab, a bottom crack was artificially simulated by a similar folded metal plate (inverted V-plate) placed under the *X-FLEX* at the joint location.

4.3.3 Test Data and Experimental Results

FWD tests were performed for each of the three slabs at the start of the experiment, after 1.2 million load repetitions, and after 2.2 million cycles. The first 1.2 million cycles were at 89 kN

(20,000 lbs) on each actuator for all three slabs, and subsequent loads were at 178 kN (40,000 lbs). This test is shown in Figure 29. The first 1.2 million load repetitions had a 178 kN (40,000 lbs) load applied at the center of a cross beam acting on both the North and Middle slabs simultaneously (not shown in the figure). This resulted in 1.2 million repetitions of 89 kN (20,000 lbs) or half the applied load on each of these two slabs. The tests where stopped at 2.242 million repetitions for shortage of time.

The purpose of this test was to compare the behavior and the deflection of the three different types of shear transfer devices. The experiment was performed to suit the needs of Cardwell Concrete Systems. The test setup was established following the experiment as designed and requested by Cardwell. This service was mainly performed in return to the company donation to KSU of the test machine (frame, wheel assembly, control mechanism, etc.) and technical support. Therefore results of these tests, as well as those performed in El Dorado on the related small scale specimens, are proprietary to Cardwell Concrete and will be made available and published at the discretion of the company. Request for results data should be submitted to the company.

Figure 26. Rutting of the Asphalt Pavement at the Wheel Paths

Figure 27. Severe Rutting after Rehabilitation

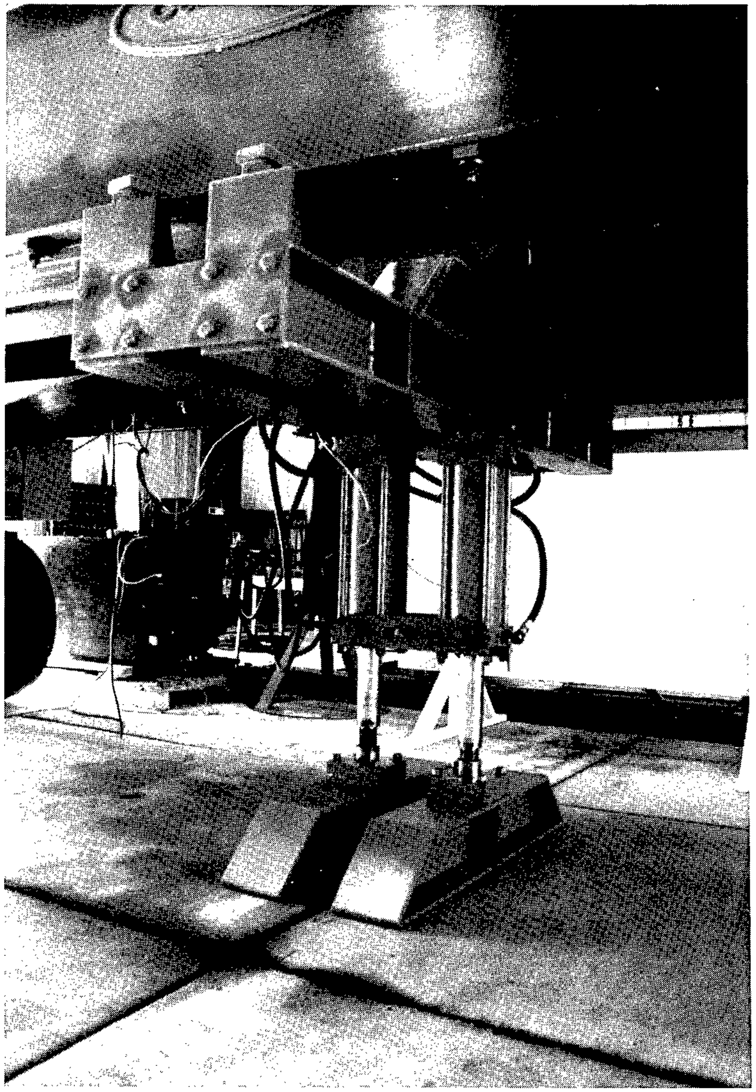

Figure 29. Testing PCCP Joint with FiberCon
(Photo taken by KSU Photographic Services)

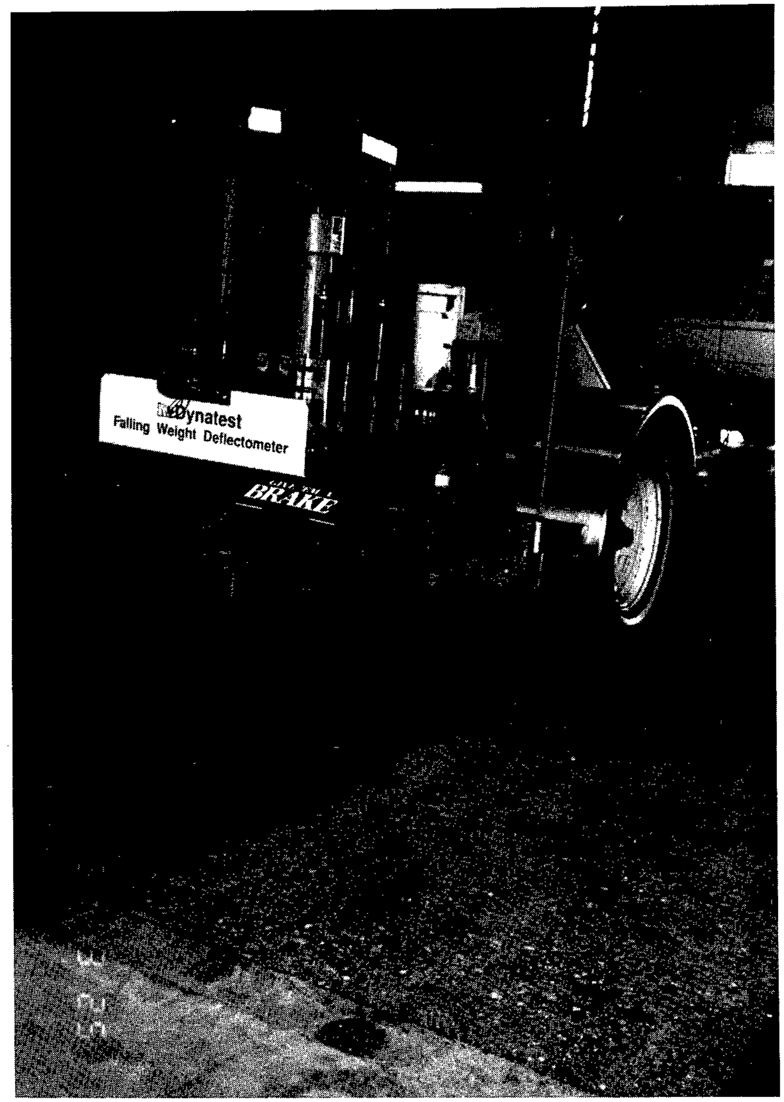

Figure 28. FWD Testing of the Pavement Specimen

5.0 CONCLUSIONS AND FUTURE ACTIVITY

5.1 Conclusions

The activity pertaining to the development of an Accelerated Testing Laboratory at Kansas State University for testing pavement and highway materials has been very successful. The resulting laboratory has much better features and capabilities than originally planned. Many of the improvements to the initial design are a direct result of the diligent activity of the Advisory Committee formed at an early stage of the project. Suggestions and recommendations of the committee resulted not only in a larger and better equipped laboratory, by also in a facility with more flexibility and capabilities to perform a variety of tests under diverse loading and environmental conditions.

These advanced and more elaborate features of the lab required additional time, effort, and costs to achieve the goal of a developing a laboratory of much superior quality than initially anticipated. The 12-month duration originally estimated for the project resulted in a little more than 3 years activity. However, the additional time, costs, and efforts are considered much appropriate in view of the resulting accomplishment. Kansas State University and the State of Kansas now have a one-of-a-kind accelerated pavement testing laboratory of the finest grade that can be considered a regional/national facility. The facility can be of service to many states and industries in the country and can produce very useful results of interest to the national and international highway communities.

The tandem axle assembly of the K-ATL moving at 8 km/h (5 mph), or a pulse load system with hydraulic actuators, can apply up to 178 kN (40,000 lbs) on flexible or rigid pavement specimens 6.1 m (20 ft)-long and up to 6.1 m (20 ft)-wide. Environmental and temperature control features allow a section of pavement to be heated or cooled either from the top or from the bottom in a 3.7 m×6.1 m (12 in.×20 in.) environmental pit. Temperature ranges between −23°C and +66°C (−10°F and +150°F). Water level is controlled through a sprinkler/drainage system in the test pits that are 1.8 m (6 ft)-deep and insulated with a waterproof membrane.

Two experiments were conducted at the K-ATL in the first half of 1997. They demonstrated the capability of applying a tandem axle wheel loading of 151 kN (34,000 lbs), --although a load up to 178 kN (40,000 lbs) can be achieved--, on an asphalt pavement and an alternating pulse load of 178 kN (40,000 lbs) on three types of PCCP joints. In the first experiment a total of 168,000 load repetitions (truck passages) were applied to the pavement at a rate of 616 application per hour. In the second set of experiments, a total of 4.7 million load cycles of the testing machine were applied at a rate of 9000 repetitions per hour. This resulted in 5.9 million load repetitions in a combination of 89 kN (20,000 lbs) and 178 kN (40,000 lbs) load applications on the specimens.

These experiments helped debug the system, modify the individual components, and evaluate the testing capabilities and limitations of the system. A time estimate to conduct the different types of tests has been established. In addition, a schedule of charges has also been established based on the testing and research activity deployed during this project. The charges include fees for the five following types of activities:

1. Usage of pavement testing machine with wheel assembly (bogies). One or two axles, up to 8 wheels, maximum total load 178 kN (40,000 lbs), one- or two-way truck passage, up to about 5 cycles per minute (300 cycles/hr).

2. Usage of pulse load assembly (thumper) with hydraulic actuators. Maximum load 178 kN (40,000 lbs), up to 2.5 cycles per second (9000 cycles/hr).

3. Heating with glycol system and boiler. Top and/or bottom loops, up to +66°C (150°F).

4. Cooling/Freezing with glycol system and chiller. Top and/or bottom loops, down to -23°C (-10°F).

5. Surface heating with infrared radiant heaters. Up to +50°C (122°F) - (estimated).

The schedule of charges has been submitted to the University Administration and has recently been approved. Details of these charges can be obtained by contacting the author of this report at Kansas State University.

5.2 On-Going Activities

At the last meeting of the Advisory Committee interest was expressed by the FHWA Region 7 States to create a regional pooled fund to perform accelerated testing. Consequently, the Midwest States Accelerated Testing Program and associated Technical Committee were formed. A memorandum of understanding was signed between KDOT and the DOT's in Iowa, Missouri, and Nebraska.

This Technical Committee includes one person from each agency and representatives of the Federal Highway Administration for each of the member states in the consortium. The purpose of the committee is to identify most urgent research needs, establish a priority and selection process, and design the selected experiments. The committee met on April 30, 1997 and developed the testing program for FY 1997.

5.3 Future Tests

For future tests, a set of stronger beams, designed to higher fatigue strength and less deflection, have been fabricated and are ready to use. The new design is shown in Figure 30.

A more sophisticated system for the pulse load device (thumper) is needed to achieve a smoother testing operation with closed-loop load-control testing. This system will result in a safer operation, more reliable results, and less maintenance and test interruptions. This modification is presently being investigated.

The research ideas considered by the Technical Committee for future activity include the following:

1. Compare 203 mm (8 in.) AC with 127 mm (5 in.) AC on 127 mm (5 in.) RAP
2. Mill 51 mm (2 in.) from previous test and replace with 51 mm (2 in.) RAP
3. Compare "optimum" and "optimum + 0.5%" binder content on Superpave SM-2C mix.
4. Compare 152 mm (6 in.) Superpave SM-2C with conventional BM-2C both at optimum binder content
5. Compare Superpave SM-2A and SM-2C both at optimum binder content
6. Compare fiber composite vs. epoxy coated steel dowels in a 203 mm (8 in.) PCCP (plain) with fixed ends.
7. Compare 152 mm (6 in.) PCCP conventional mix with 152 mm (6 in.) PCCP with 3M polypropylene fibers both without dowels and with fixed ends.

An agreement was reached to perform testing during FY 1997. The two experiments agreed upon for the second half of 1997 are described below (excerpts from the signed agreement).

"Experiment 1 - Testing Superpave versus Marshall Mix

The Technical Committee decided (in its April 1997 meeting) to place 102 mm (4 in.) overlays over the existing concrete section after the Cardwell testing is completed, and compare Superpave SM-2C mix design with Marshall (conventional) BM-2C mix designs under wheel loads. This experiment will constitute Task 3 of this proposal. The subbase will be stabilized at optimum +2% moisture content and the pavement will be heated to 50°C (122°F) from the surface with radiant heaters. The two different types of mixes will be tested side-by-side as two adjacent strips 1.5 to 1.8 m (4.5 to 6 ft) wide and 6.1 m (20 ft) long, loaded each with one half tandem axle. The design of the mixes will follow the guidelines recommended by the FHWA Accelerated Pavement Testing (APT) Expert Task Group (ETG) for Superpave experiment design as shown in the Appendix at the end of this proposal. The load should be 151 kN (34,000 lbs).

Each of the two 6.1 m (20 ft) strips will be divided into two sections placed parallel to the direction of the rolling wheels. The two sections will consist of mixes prepared with optimum and optimum +0.5% binder content. This experiment will be conducted in the large pit (6.1 m× 6.1 m×1.8 m) of the K-ATL. It is expected that this test will require 100,000 load repetitions.

Experiment 2 - Testing Fiber Composite versus Epoxy Coated Steel Dowels

The second experiment decided upon by the Technical Committee is the comparison of PCCP dowel joints with plastic fiber composites versus epoxy coated (conventional) steel dowels. Two 203 mm-thick (8 in.) adjacent slabs, each with one of the two types of dowels and separated by a construction joint, will be tested simultaneously. The total load on both strips will be between 151 and 178 kN (34,000 and 40,000 lbs). The edges of the PCCP section should be tied down at the two ends perpendicular to the direction of traffic. The thermal system will be used to cause warping of the slab and joint movement. The environmental pit will be used for this experiment.

It was proposed to use the pulse loading device (thumper) to apply the cyclic loads on the test specimens. It is expected that this experiment will require at least 1 million load applications. The usage of rolling loads (wheel assembly) together with the heating and cooling equipment will make the experiment significantly longer and much more expensive."

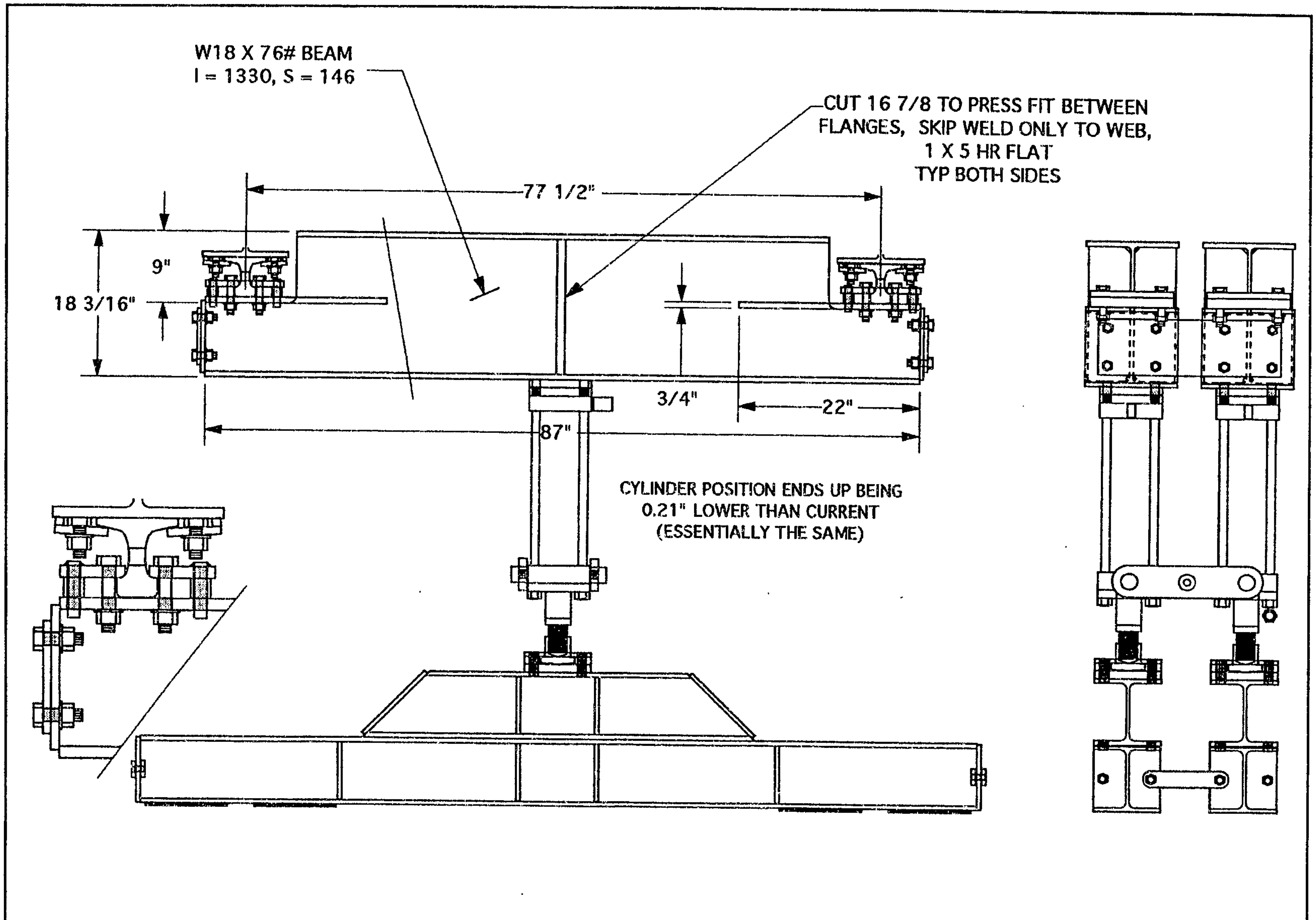

Figure 30. Replacement Beams for the Pulse Load System
(Drawing provided by Cardwell Concrete Systems

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Melhem, H.G., "Accelerated Pavement Testing in Kansas," presented at the 86th Annual Mississippi Valley Conference of the American Association of State Highway and Transportation Officials, AASHTO, June 12-14, Chicago, Illinois, 1995.

Melhem, H.G., Hossain, M, Xu, J.C., and Gisi, A.J., Testing of Cold In-Place Recycled Pavement at the Kansas Accelerated Testing Laboratory, submitted for presentation and publication at the 1998 Annual Meeting of the Transportation Research Board, January 1998, Washington D.C.

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White, T.D., Albers, J.M., and Haddock, J.E.Sr., "An Accelerated Testing System to Determine Percent Crushed Aggregate Requirements in Bituminous Mixtures," Interim Report, FHWA/IN/JHRP-90/8, Purdue University, West Lafayette, IN, May 1990.

APPENDIX A

ATL Advisory Committee

Committee Chair and Project Monitor:

Richard L. McReynolds, KDOT

Committee Members:

Ramon Bonaquist, U.S. Federal Highway Administration
G. Norman Clark, KDOT, Bureau of Materials and Research, Geotechnical Unit
Glenn Fager, KDOT, Bureau of Materials and Research, Research Unit (Bituminous)
Andrew Gisi, KDOT, Bureau of Materials and Research, Soils and Pavement Section
Richard Griffin, Colorado Department of Transportation
Kenneth Hurst, KDOT, Bureau of Design, State Bridge Office
Thomas Keith, Missouri Department of Transportation
William Klassen, Federal Highway Administration, Kansas
Brian McWaters, Iowa Department of Transportation
James Murray, Missouri Department of Transportation
Thomas Pickford, Kansas Asphalt Pavers Association (KAPA)
Larry Senkowski, Oklahoma Department of Transportation
Steve Tritsch, American Concrete Paving Association (ACPA)
David Winter, Nebraska Department of Roads
John Wojakowski, KDOT, Research Unit (Concrete)
George Woolstrum, Nebraska Department of Roads

APPENDIX B

Facility Development Costs

Contracts, Grants, and Donations:

• KDOT[1] Initial Contract (FY 95)	$127,383	KSU Match	$40,190
KDOT - Supplement (FY 96)	$68,953	KSU Match	$25,657
- Revision (FY 96)	$2,587		
Cardwell International, Inc.[2]	$158,000		
KTEC	$100,000	KSU Match	$7,801
TOTAL GRANTS (1994 -1996)	$456,923	KSU [4]	$73,648

• Private Donations [3]	- Mar. 95	$287,500
	- July 95	$ 56,544
	- Adjustments	$ 490
	- Nov. 96	$51,045
TOTAL DONATIONS (1994 -1996)		$395,579

Notes:

(1) *KDOT support uses federal SP&R funds*

(2) *Cardwell support includes in-kind contributions for testing apparatus*

(3) *All construction and building-related costs used private donations from KSU alumni as shown below.*

(4) *The Department of Civil Engineering also spent about $5,000 on landscaping, welding equipment, tools, safety devices, and other miscellaneous items.*

Building Cost Breakdown:

General Contractor	$300,289
Mechanical Engineering Subcontract	$13,814
KPL Installation Services	$4,674
Architectural Services (KSU Facilities)	$18,702
Soil Investigations, survey, etc.	$6,341
Overhead Crane	$39,245
Forklift	$11,800
Total Building	$394,865

APPENDIX C

Research Team and Other Contributors

Research Team

Kuo-Kuang Hu, Professor, KSU Department of Civil Engineering
Hani Melhem, Associate Professor, KSU Department of Civil Engineering
Dennis Pauls, General Manager, Cardwell Concrete Systems, Inc.
Hugh Walker, Professor, KSU Department of Mechanical Engineering

KSU Faculty Consultants:

Mustaque Hossain, Associate Professor, KSU Department of Civil Engineering
Mohammad Hosni, Associate Professor of Mechanical Engineering and Director, KSU Institute of Environmental Research
Philip Kirmser, Professor Emeritus, KSU Department of Civil Engineering
Eugene Russell, Professor, KSU Department of Civil Engineering
Stuart Swartz, Professor and Head, KSU Department of Civil Engineering

KSU Other Workers

- *Technicians*: Scott Cregg (primary), and Russ Gillespie (secondary)
- *Graduate Students*: Affan Habib, Rafael Morice, Jingchen Xu, and Xinhua Yu.
- *Undergraduate Student Helpers*: Robert (Jason) Karas, Jason Hoy, Craig Finnley, Nathan Bergman, Nicholas Clough

Contractors

- *Architects* (Building): KSU Facilities Planning office, Division of Facility
- *General contractor* (Building): D.J. Carpenter Building Systems, Manhattan, Kansas
- *Heating and cooling system installation* (testing area): GMG Cooling Inc., Topeka, Kansas
- *Mechanical/electrical engineers*: Orazem &Scalora Engineering, P.A., Manhattan, Kansas
- *Asphalt specimen preparation*: Schilling Construction Co., Inc., Manhattan, Kansas
- *Soil compaction and concrete specimen preparation*: Bayer Construction Co. Inc., Manhattan, Kansas.