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Contract value	0.00	48,612.00
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Title: DEV OF MODIFIED LOADED WHEEL TESTING MACHINE FOR EVALUATING RUTTING OF ...

PROJECT ADMINISTRATION DATA

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Administrative comments -
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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

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Closeout Notice Date 10/21/93

Project No. E-20-X06

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Project Director LAI J S

School/Lab CIVIL ENGR

Sponsor GA DEPT OF TRANSPORTATION/

Contract/Grant No. TASK ORDER 26 UNDER BOA 90 Contract Entity GTRC

Prime Contract No.

Title DEV OF MODIFIED LOADED WHEEL TESTING MACHINE FOR EVALUATING RUTTING OF ..

Effective Completion Date 930831 (Performance) 930831 (Reports)

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Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
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Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Management	Y
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Reports Coordinator (OCA)	Y
GTRC	Y
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	N

NOTE: Final Patent Questionnaire sent to PDPI.

Contract Research
"GDOT Research Project NO. 9201

FINAL REPORT

Development of a New Loaded Wheel Testing Machine
for Evaluating Rutting of Asphalt Mixes

by

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Prepared for

Department of Transportation
State of Georgia

July, 1993

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

EXECUTIVE SUMMARY

Development of a New Loaded Wheel Testing Machine for Evaluating Rutting of Asphalt Mixes

The objective of this proposed research project was to develop a semi-automatic loaded wheel testing machine and a rolling compaction machine which incorporated various improvement ideas suggested by various current users. The following summarize the improvement features of these two machines.

LOADED WHEEL TESTER

- (1) The loaded wheel testing can be semi-automatically controlled. By presetting the number of repetitions, the test will run and stop when the preset number of repetitions is reached.
- (2) The machine is able to test three 5 in wide beam samples simultaneously.
- (3) The machine is capable to test a 18 in. wide slab sample.
- (4) The machine has the option of testing samples under water.
- (5) Temperature control is more accurate and consistent and can be adjustable to 140 °F.
- (6) The machine can also used to preheat 3 beam samples during normal testing.
- (7) The tire or hose pressure and the magnitude of the wheel load can be adjusted to higher level.
- (8) A digital indicator is used for rut profile measurements. The indicator is capable of interfacing with a computer.

ROLLING COMPACTION MACHINE

- (1) The machine is relatively compact and self contained.
- (2) Beam sample compaction simulates the rolling action of a rubber tire roller.
- (3) Beam sample preparation is easier and more consistent beam density can be obtained.

These two machines developed from this project are easy to use, can generate more reliable results and are suitable as a routine asphalt testing facility for evaluating rutting characteristics of asphalt mixes.

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CHAPTER 1 INTRODUCTION

Rutting of asphalt pavements has a major impact on pavement performance. Rutting reduces the useful service life of the pavement and, by affecting vehicle handling characteristics, creates serious hazards for highway users. This excessive rutting in asphalt pavements becomes a major concern in many parts of the United States due to the ever-increase in magnitude and in number of repetitions of the axle loads. The use of radial tires which develop high tire pressure also contributes to the serious rutting problem.

Marshall mix design method and Hveem mix design method are two commonly used methods for the design of asphalt mixes. Although asphalt mixes designed by these two methods most likely can eliminate extremely unstable mixes, there is no assurance that an asphalt mix satisfying the design criteria of either one of these methods will not develop unacceptable rutting under normal traffic conditions. Thus, there is increased interest in developing mixture evaluation procedures which will be more responsive and can better assess the rutting characteristics of asphalt mixes. A recent report from the Strategic Highway Research Program (SHRP-A/IR-91-104 Summary Report on Permanent Deformation in Asphalt Concrete, by Sousa, Craus and Monismith) described various laboratory test methods for permanent deformation evaluation. Unfortunately most of the methods lack the field verifications.

Recognizing the need to have a simple testing procedure which can be used to supplement the current Marshall mix procedures for obtaining asphalt mixes with better rutting resistance, Dr. Lai of Georgia Tech,

working closely with the GaDOT, has developed a wheel tracking machine (Loaded Wheel Tester, LWT) and the testing procedure for evaluating the rutting characteristics of asphalt mixes. The initial version of the LWT has been used extensively for five years by GaDOT. The results have demonstrated good field verifications. In 1990 the Federal Highway Administration, Office of Technology Applications sponsored a round-robin testing program, participated in by six state highway departments, to evaluate and verify the applicability of this testing method. Judging from the laboratory and the field verification results, it has shown that using the loaded wheel testing as a supplement to the Marshall mix design can provide a simple, practical and yet accurate means of evaluating the rutting characteristics of asphalt mixes.

When the LWT program was originally developed, the emphasis was primarily to evaluate the applicability of the concept rather than the refinement of the machine itself. We recognized then that the machine would have to be modified if and when the LWT testing concept has proven to be viable. With the concept of the LWT testing has proven to be viable, and the testing has been used extensively by GaDOT and by several other State DOT's in the past several years, it is desirable to modify the LWT machine to improve the operational characteristics of the machine and make it more suitable to be used as a routine laboratory test apparatus. An interim research study sponsored by Georgia DOT to assess the various desirable improvement ideas has been completed. The ideas developed in that study became the basis for this proposed research project for developing a new loaded wheel tester for evaluating the rutting characteristics of asphalt mixes and a rolling compaction machine for

preparing the asphalt beam samples which can better simulating the rolling action of a rubber tired roller.

CHAPTER 2 DEVELOPMENT OF LOADED WHEEL TESTER

In the original proposal for this research project, several improvement features for this new loaded wheel tester were listed along with the schemes to implement these improvement features. The original improvement ideas were further refined in the course of design and fabricate the new loaded wheel tester. The following are the improved features of the new loaded wheel tester over the current version.

- (1) The loaded wheel testing can be semi-automatically controlled. By presetting the number of repetitions, the test will run and stop when the preset number of repetitions is reached.
- (2) The machine is able to test three 5 in wide beam samples simultaneously.
- (3) The machine is capable to test a 18 in. wide slab sample.
- (4) The machine has the option of testing samples under water.
- (5) Temperature control is more accurate and consistent and can be adjustable to 140 °F.
- (6) The machine can also used to preheat 3 beam samples during normal testing.
- (7) The tire or hose pressure and the magnitude of the wheel load can be adjusted to higher level.
- (8) A digital indicator is used for rut profile measurements. The indicator is capable of interfacing with a computer.

The new LWT machine basically consists of the following four components:

- A. Wheel tracking system
- B. Loading system
- C. Rutting measurement system
- D. Operation and temperature control system

The new LWT as shown in Fig. 1 has the overall dimensions of 56 in. long by 35 in. wide by 43 in. height (48 in. including the height of the air cylinders). The details of each components of the machine are presented in the following sections.

(A) Wheel Tracking System

The wheel tracking system is shown schematically in Fig. 2 and 3 (shaded areas). The figures show that three 5 in. wide beams can be simultaneously driven by a common reciprocating driving assembly, which consists of a motor, a gear reducing box and a specially designed cam system. The reciprocating driving assembly drives the sliding plate assembly (Fig. 4) which rolls back and forth along two tracks made of unistrut sections. The top of the sliding plate holds three rubber hoses at the positions directly under the loading wheels. The beam sample holder plate (Fig. 5) which holds the asphalt beam samples and the beam sample constraints is placed directly on top of the sliding plate and is secured during the testing. The beam sample holder plate and the beam samples secured on top of it can be pulled out transverse to the direction of the reciprocating motion. This allows an easy access for placing the beam samples during the set up and for taking rut depth measurements on the beam samples after the testing.

(B) Loading System

Loading applied on the beam samples is by means of three pneumatic cylinders (Fig. 6 and 7). Each cylinder is attached with an aluminum wheel with its concave surface rolled on the pressurized rubber hose. Figure 8 shows schematically the loading control circuit. The magnitude of the wheel load applied on each beam sample is generated by the pneumatic cylinder which is regulated by a pressure regulator. Each cylinder is controlled by a separate ball valve thus allowing can be turned off independently. Pressure in three rubber hoses is regulated by a common pressure regulator, so that the pressure in three hoses will always be the same.

(C) Rutting Measurement System

Figure 9 shows the rut depth measurement device. the system consists of a measurement stand and a electronic indicator. The measurement stand has 5 slots at 2 inches apart. The base of the stand sits on top of the beam sample lateral constraints and has a protruded section which fits into a notch on the top of the lateral constraints. This arrangement ensures that the measurement stand can always be placed at the same position with respect to the beam sample. The electronic indicator has the sensitivity of 0.0005 in. or 0.01 mm. The operation of the indicator is virtually identical to that of a mechanical dial gage. This electronic indicator has several additional features and can be directly connected to a processor for storage, process and printout the data. The processor also serves as the interface with a host computer via RS-232 cable.

(D) Operation and Temperature Control

The entire machine except the motor and the gear reducer is enclosed in a environmental chamber, see Fig. 1. The environmental chamber made of insulation panels with aluminum skin insulated inside with 3/4 in. rigid

foam insulation board. Each insulation panel is attached to the steel frame and can be individually detached for easy access to the interior of the machine. The front panel has a hinged door with a viewing window. This door is used to access to the beam sample holding plate for reaching the beam samples during the set up and for the rut depth measurements.

All the heating elements and the temperature circulation and control are attached on the inside of the back and the right panels, see Fig 10. The temperature in the chamber can be set and regulated by a thermostat. In addition, a separate temperature indicator with a temperature probe inserted into a dummy asphalt beam sample allows temperature in the asphalt samples to be monitored. It has determined that this environment chamber can maintain the temperature up 140 °F with a 2 °F fluctuation.

All the controls for operating the loaded wheel test are mounted on the control box on top of the machine, see Fig. 1 and Fig. 11. The main feature of the operation control is to control the start-stop of the loaded wheel testing. Before the loaded wheel test is to be started, the following steps should be taken. The samples should be properly secured on the beam sample holding plate. Temperature in the beam samples should have been stabilized to the test temperature. Pressure in the hose is in the preset value (adjustable via the pressure regulator) and the pressure gage for the air cylinders has indicated the correct pressure reading. The predetermining counter has been reset to the desirable number of repetitions. With all of these properly check out, the loading "ON/OFF" toggle switch is then turned to "ON" position. This will immediately cause the air cylinders to extend and exert the predetermined magnitude of load on the rubber hoses. After 2 seconds delay, the motor will be turned on and start the reciprocating actions. Each time the sliding plate reaches

one end, it touches the limiting switch (see Fig.10). This causes the predetermining counter to count down one on the counter and also causes the totalizing counter to add one on the counter. When the predetermining counter reaches zero it will simultaneously invoke the following three actions, causes the air cylinders to release the loading and extract the loading wheels, stops the motor and stops the reciprocating motion of the sliding plate, and turns on the red light to indicate the termination of the test.

On the control panel there is a bush-bottom for adjusting sliding plate stop position. Upon open the door, this push bottom switch can be momentarily depressed to manually adjust the position of the sliding plate so that the beam sample holding plate can be positioned at the door opening. Upon release the latch, the beam sample holding plate can be pulled out partially while the sliding plate remains stationary. This will expose the beam sample rutting path from directly under the rubber hoses and allows the rut depth measurements to be taken. If the test is to be continued, then the beam sample holding plate is push back to the secure position, close the door and reset the predetermining counter to the next desirable number of repetitions and restart the loading process. Or if the test is to be terminated, then remove the beam sample constraints and the beam samples in proper sequence.

There is a load calibration switch on the control panel. When this switch is turned to calibration position, it disables all other functions associated with the normal testing and allows the individual air cylinder to be calibrated. The heating switch on the control panel is to activate the heating and the thermostat for conditioning the environmental chamber temperature.

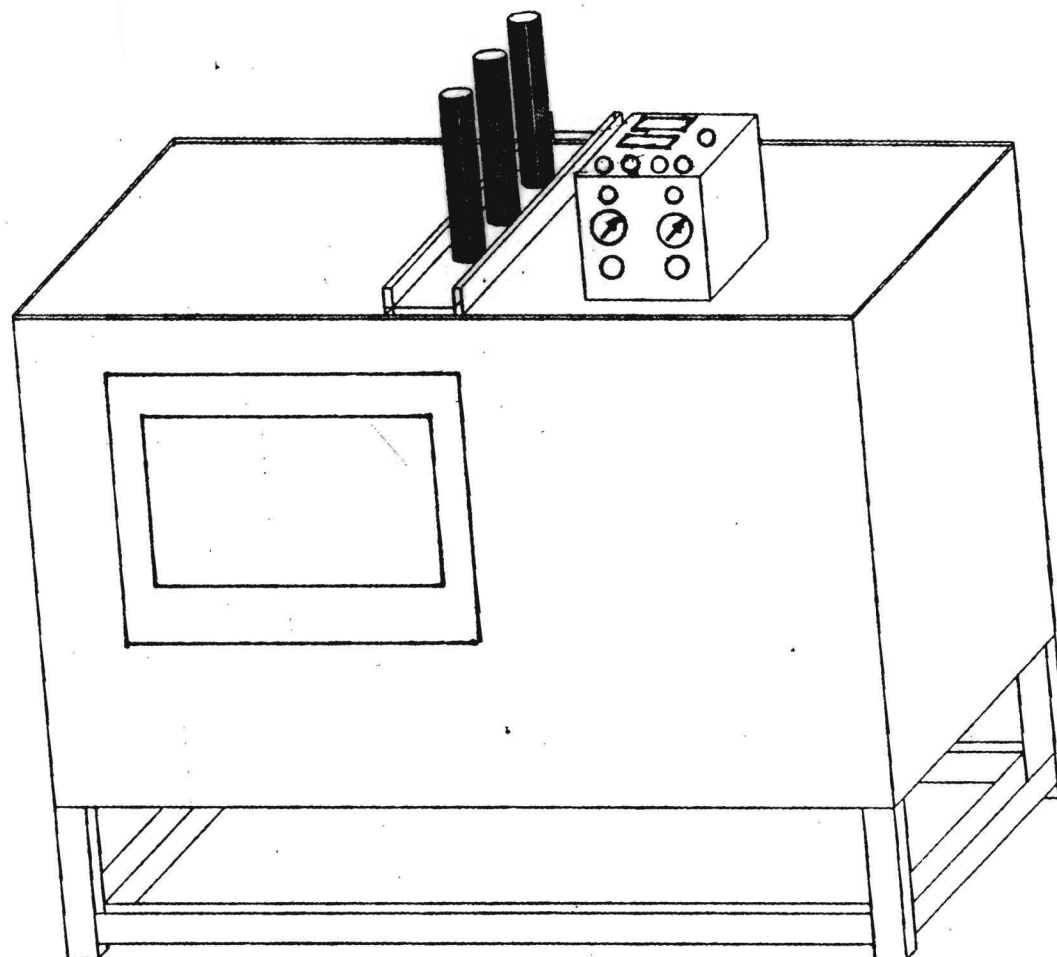


FIGURE 1. LOADED WHEEL TESTER

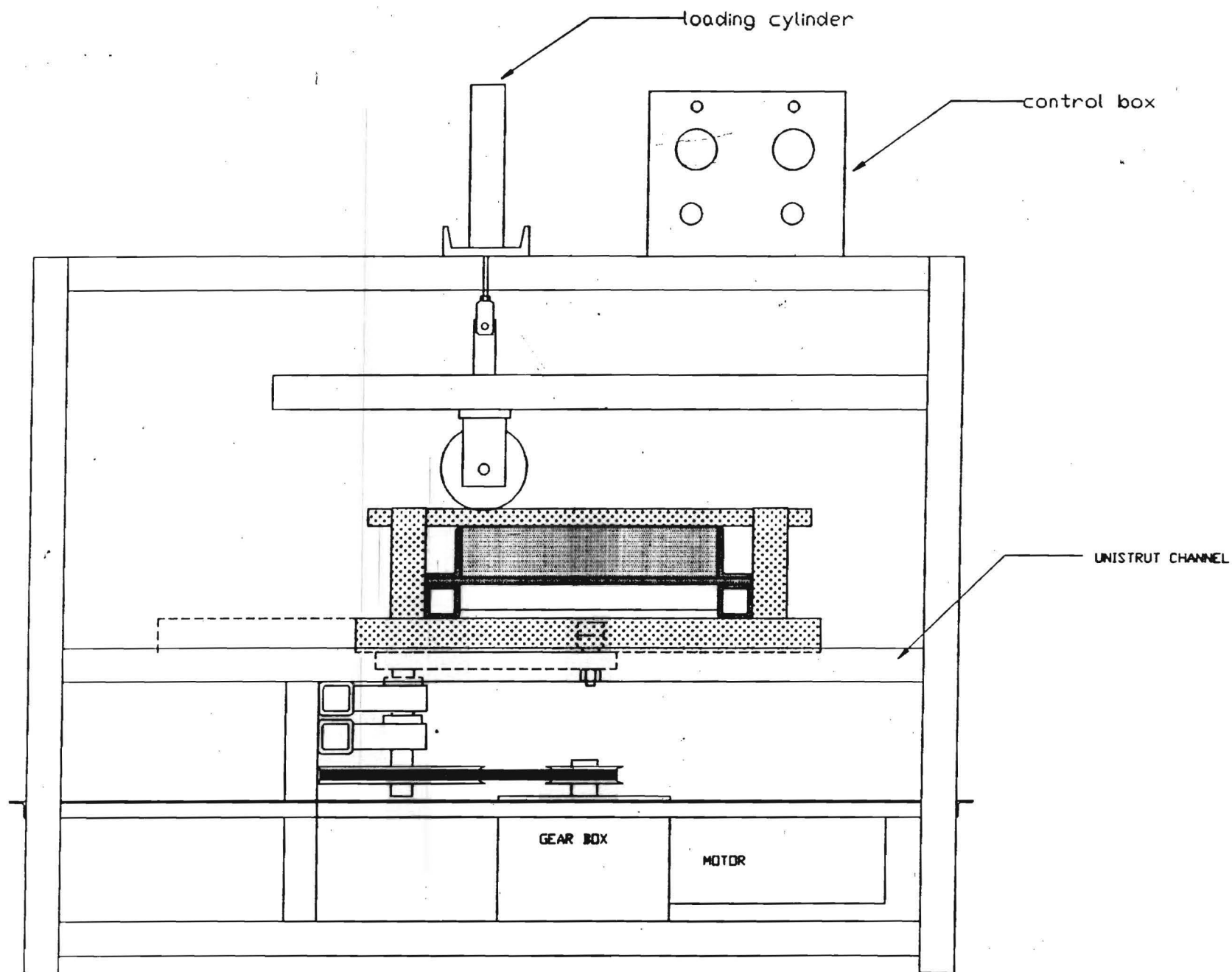


FIGURE 2 LOADED WHEEL TESTER WHEEL TRACKING SYSTEM (FRONT)

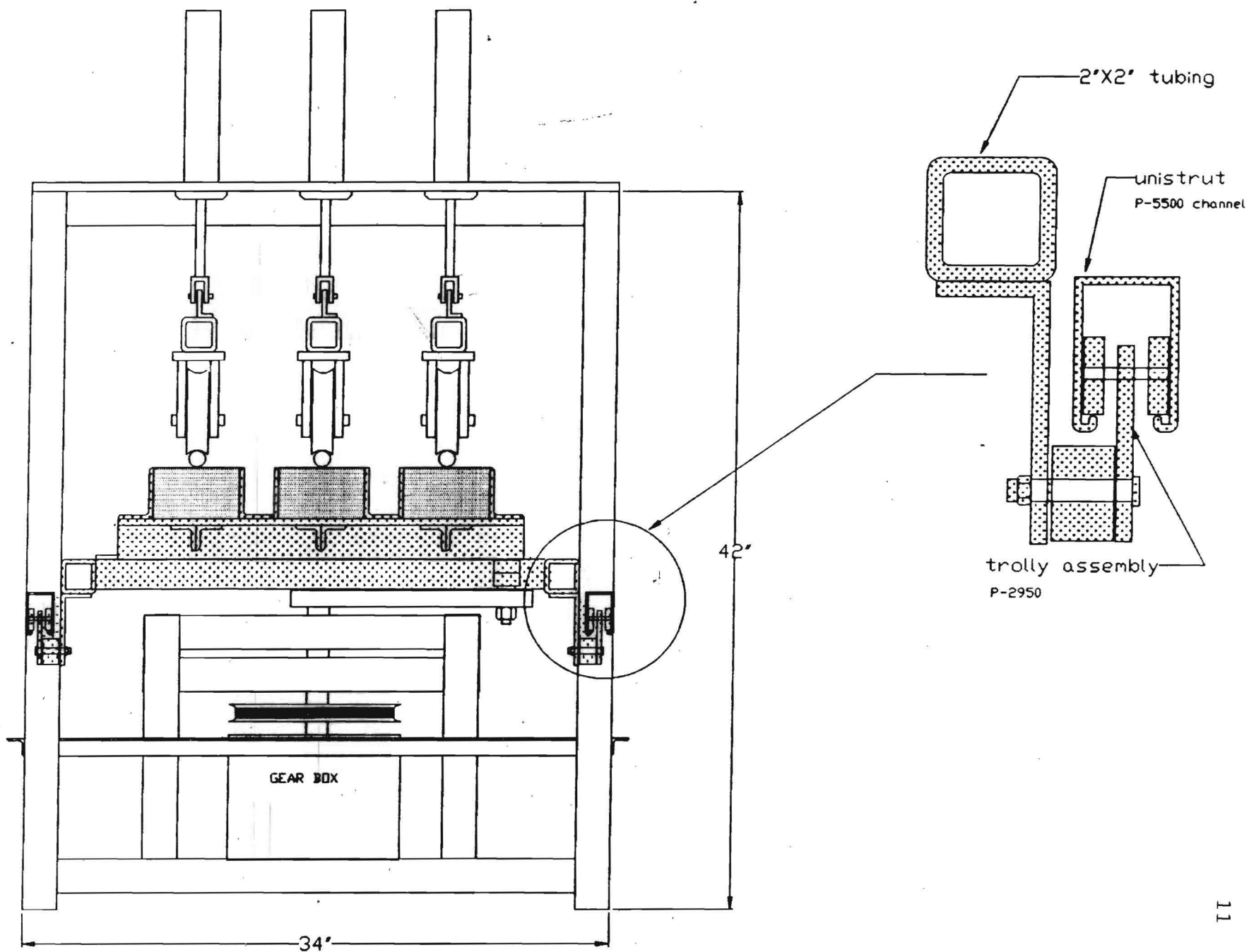


FIGURE 3 LOADED WHEEL TESTER WHEEL TRACKING SYSTEM (SIDE)

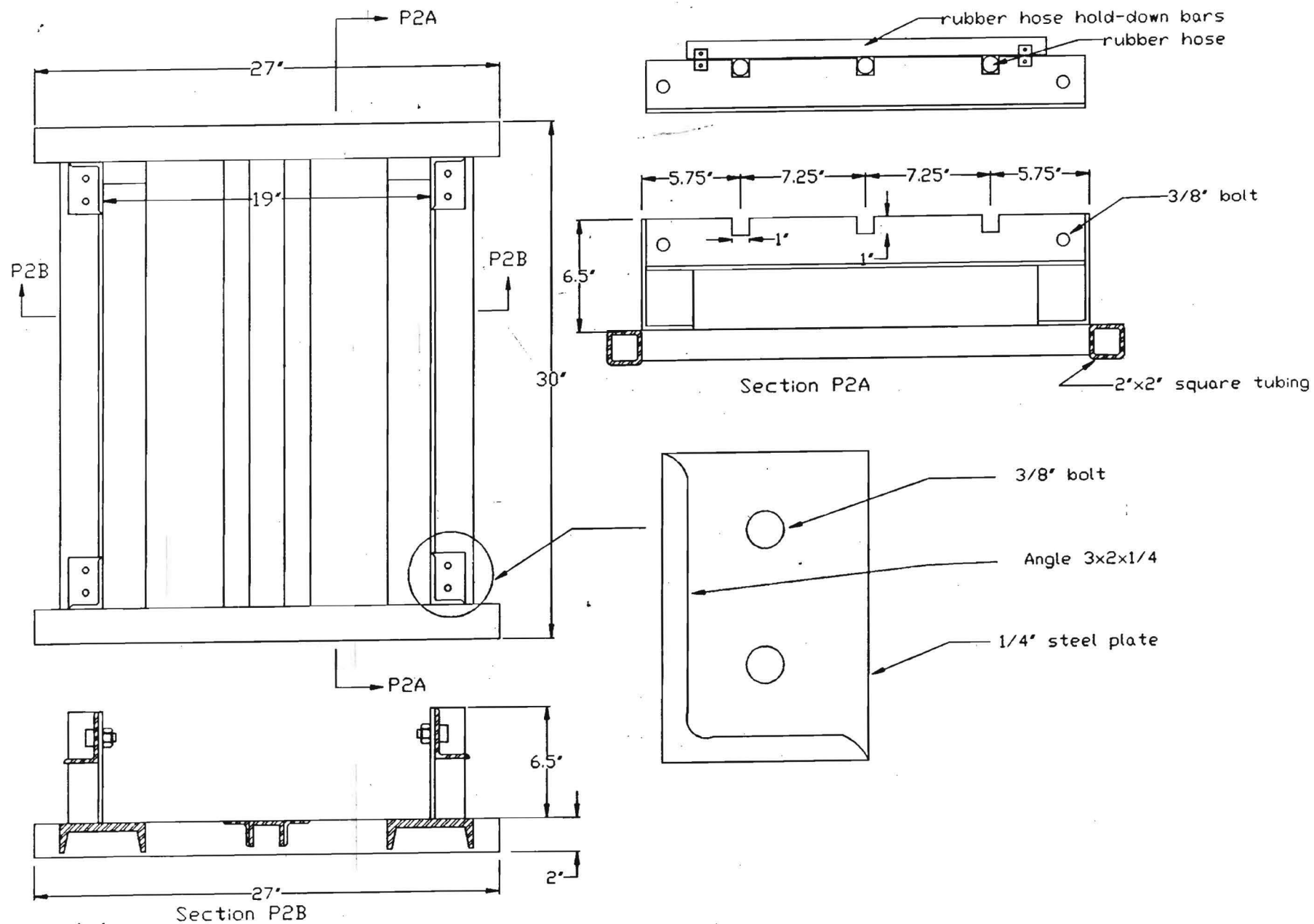
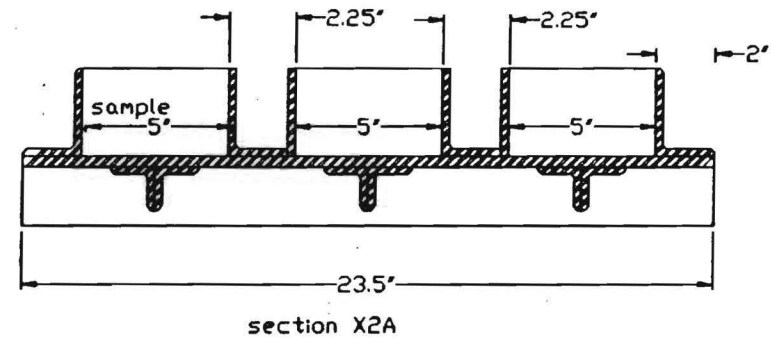
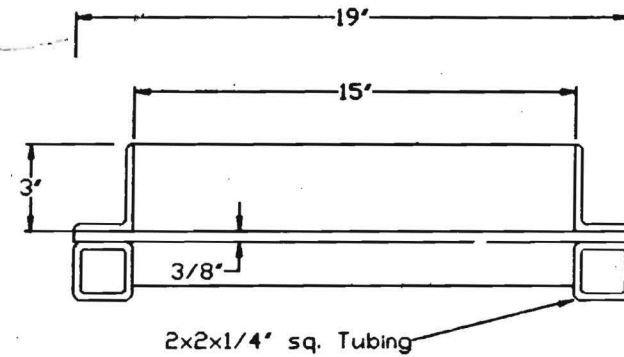
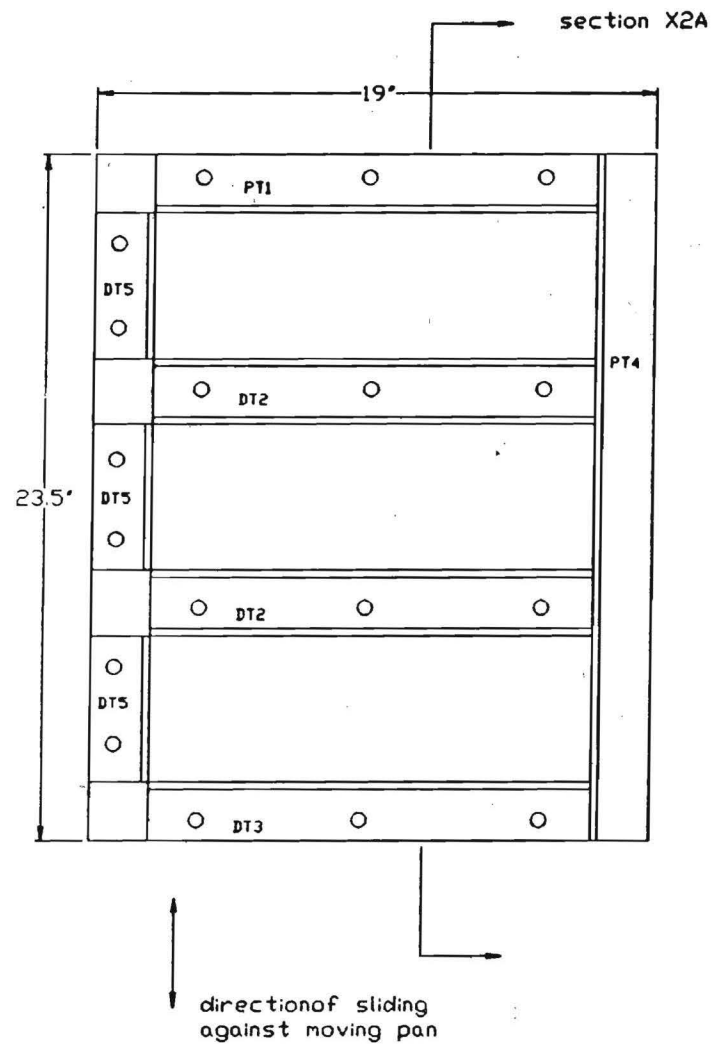


FIGURE 4 SLIDING PLATE ASSEMBLY



NOTE:

Sample tray is placed and secured on top of the moving pan. It can be pulled out to facilitate installation and removal of beam samples, and for rut depth measurements.

FIGURE 5 BEAM SAMPLE HOLDING PLATE

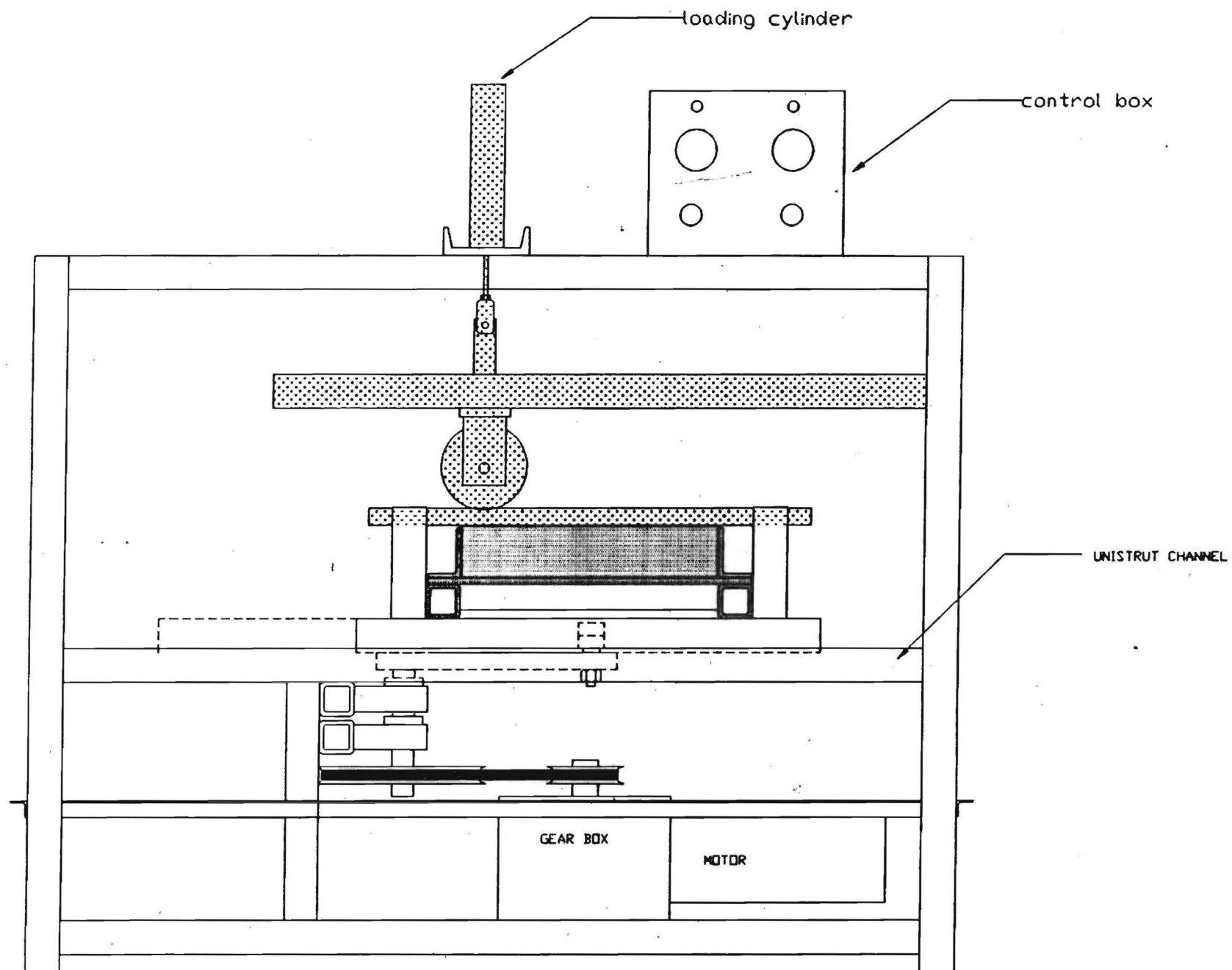


FIGURE 6 LOADED WHEEL TESTER LOADING SYSTEM (FRONT)

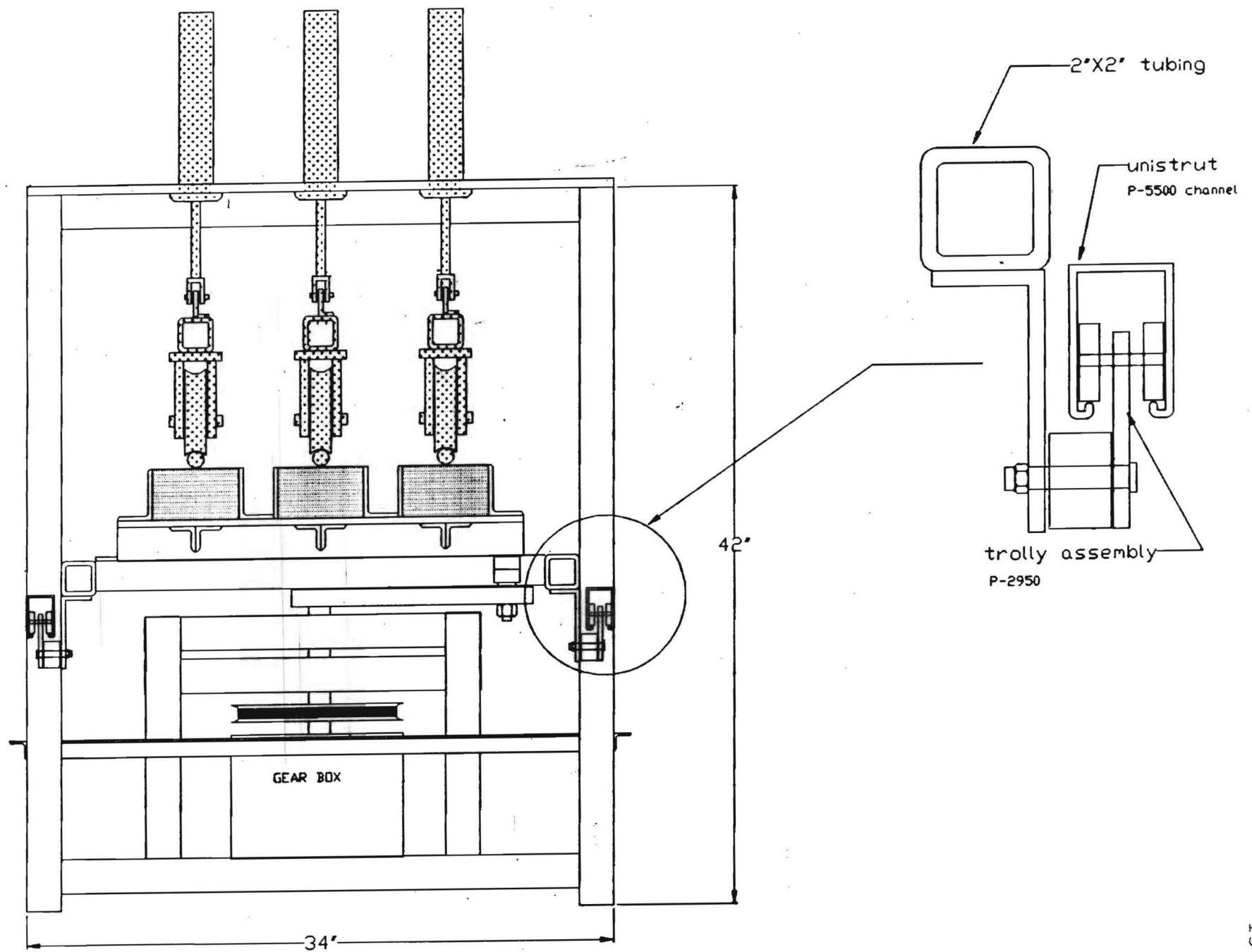


FIGURE 7 LOADED WHEEL TESTER LOADING SYSTEM (SIDE)

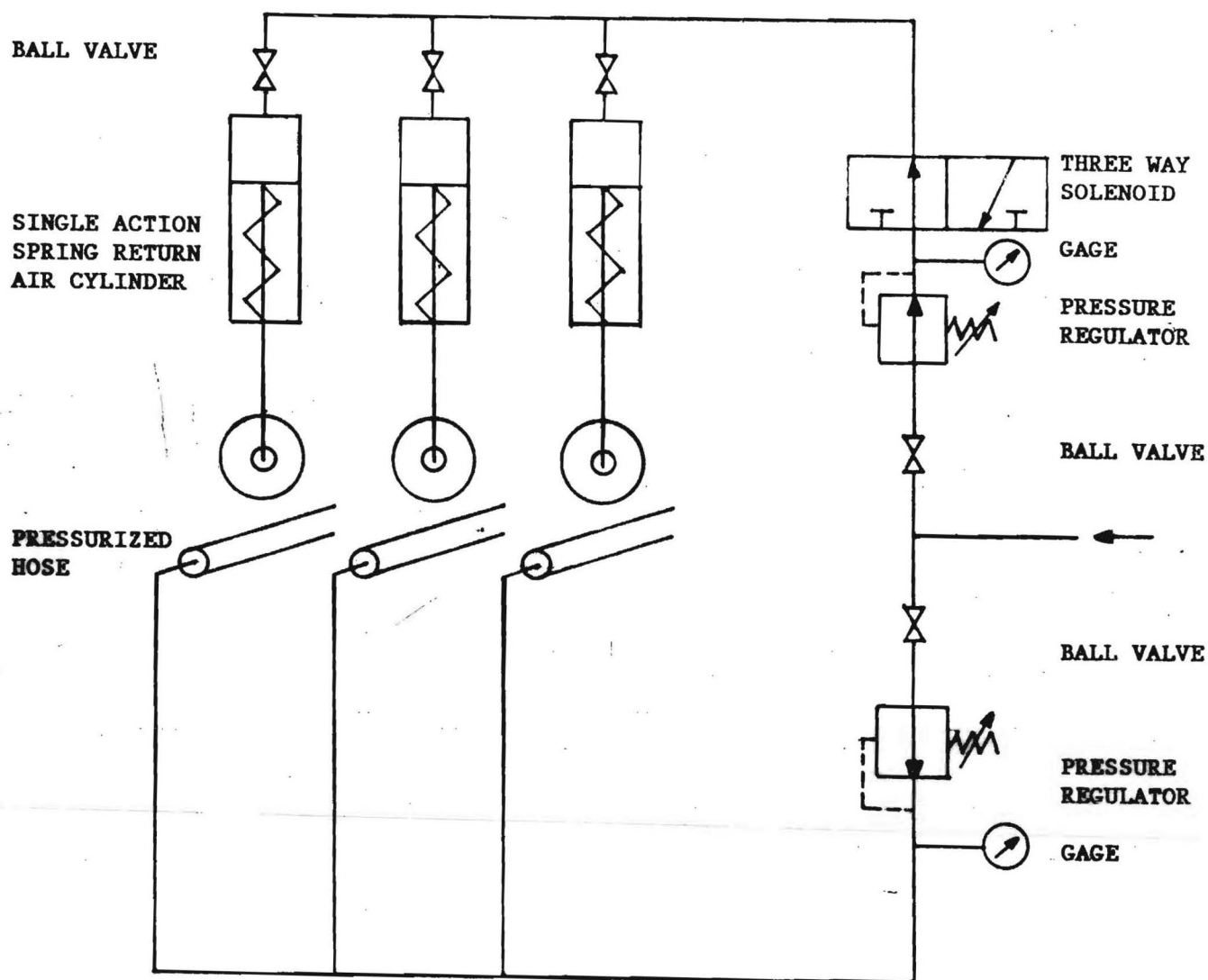


FIGURE 8 LOADED WHEEL TESTER LOADING CONTROL CIRCUIT

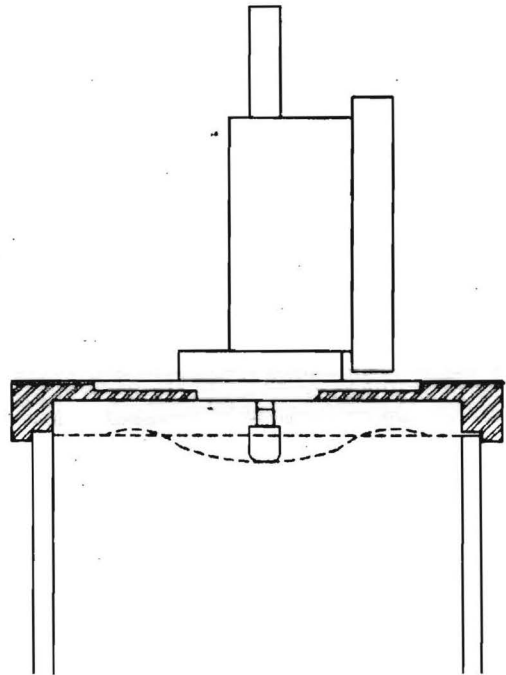
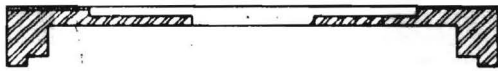
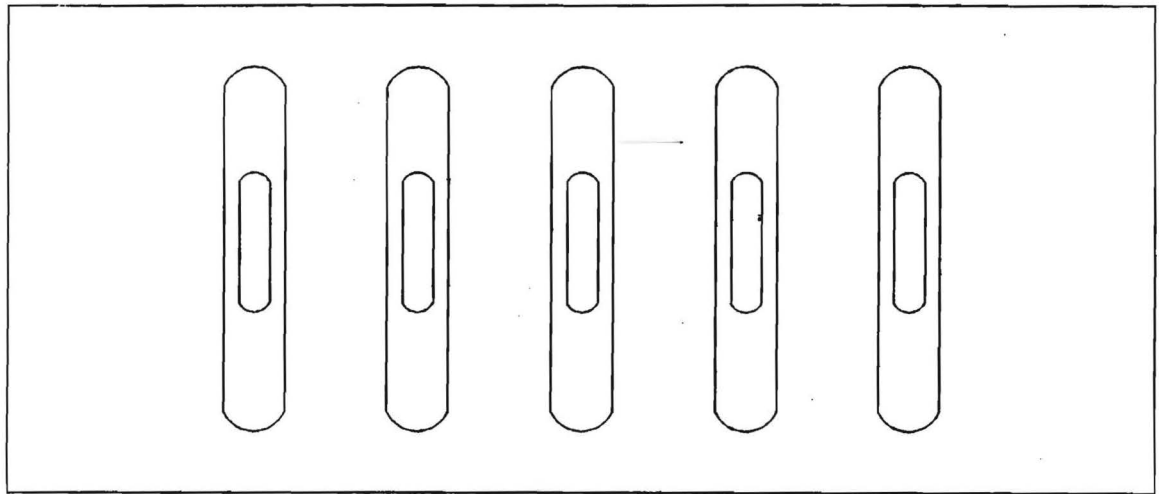
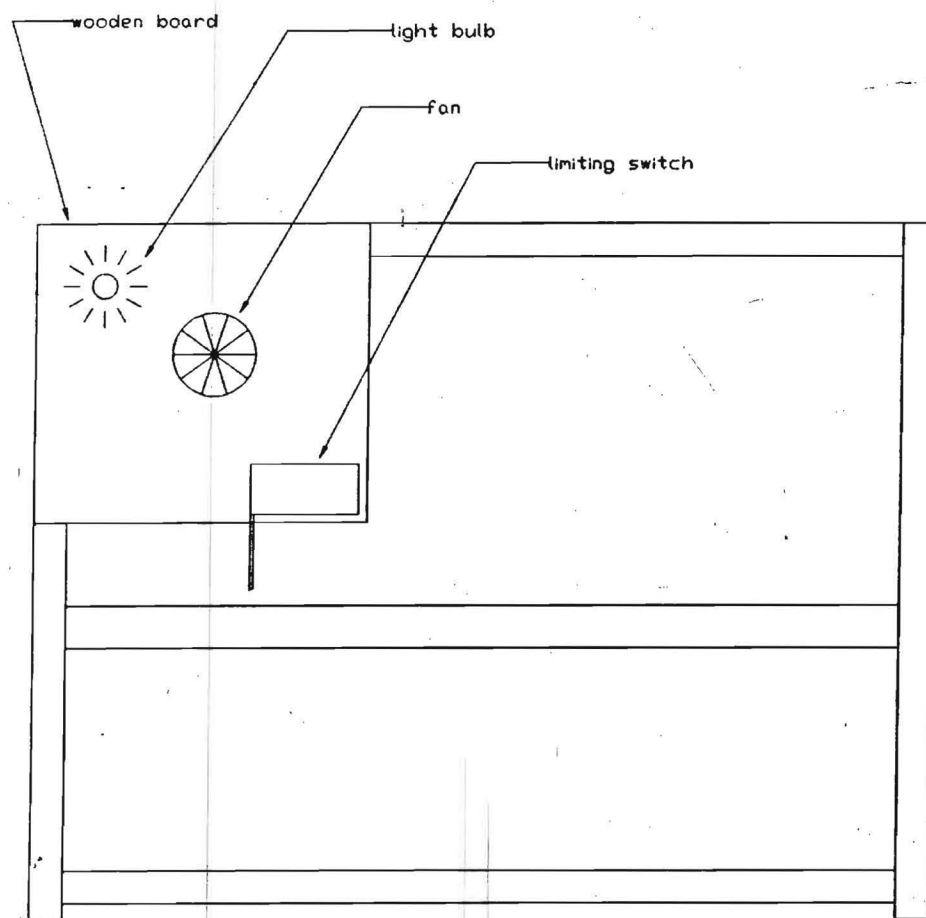
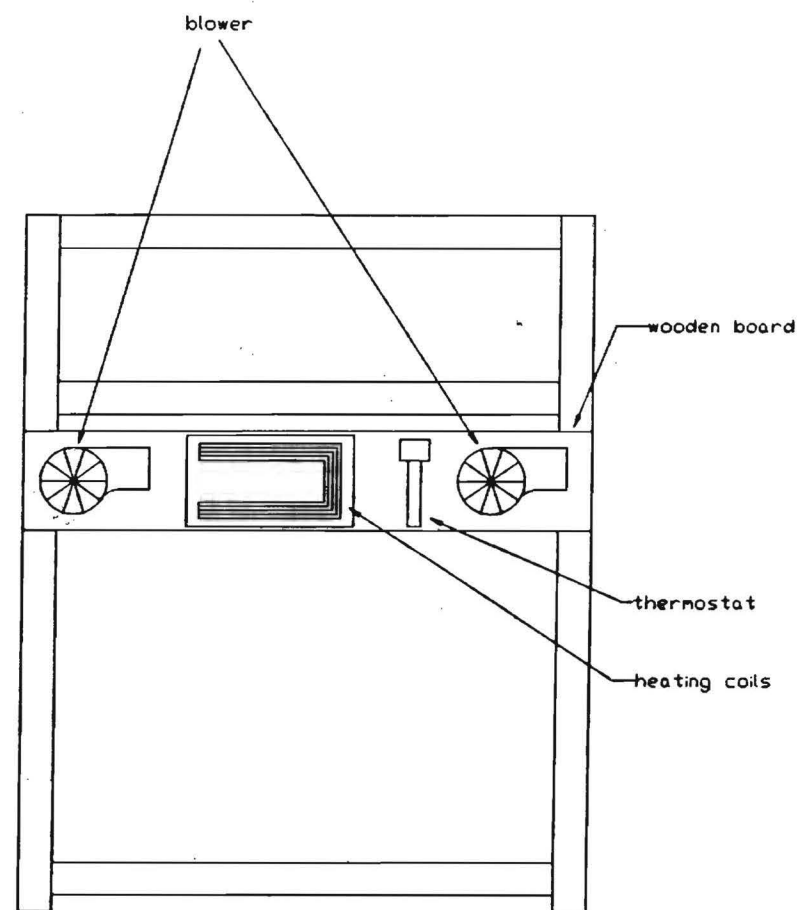


FIGURE 9 RUT DEPTH MEASUREMENT DEVICE



back panel



right panel

FIGURE 10 ENVIRONMENTAL CHAMBER TEMPERATURE CONTROL ARRANGEMENT

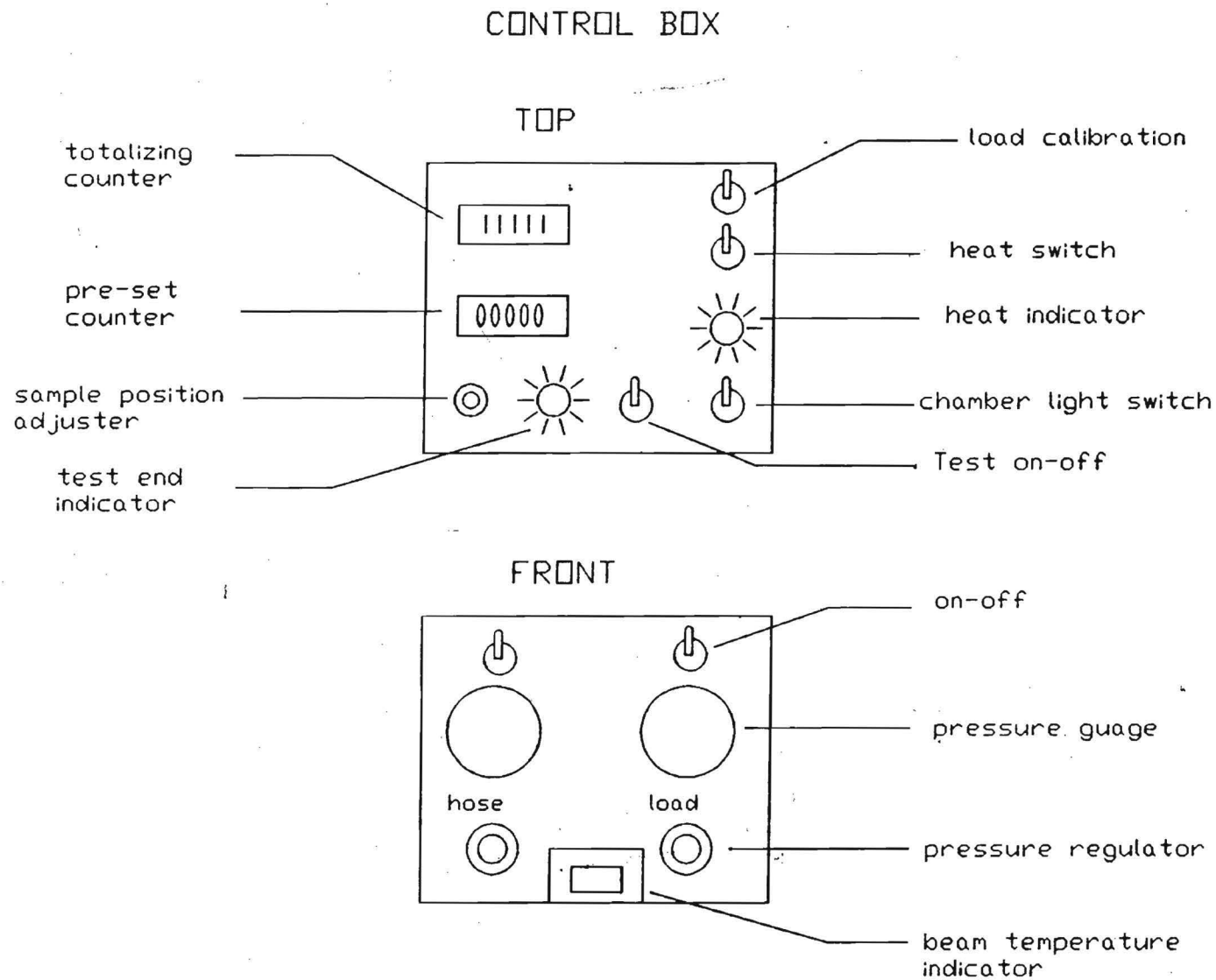


FIGURE 11 OPERATION CONTROL PANELS

CHAPTER 3 DEVELOPMENT OF ROLLING COMPACTION MACHINE

Presently the beam samples are fabricated by the a static compaction process using a compression machine. One of the advantages of using a static compression machine to fabricate the asphalt beam samples is that the machine is usually available in a testing laboratory. The static compaction procedure that has been used so far for preparing the beam samples is in general producing satisfactory density requirements, although the procedure is viewed to be too cumbersome. Furthermore, there is a concern that the static compaction procedure in fabricating the asphalt beam samples may not be able to produce asphalt samples with the properties similar to that produced in the field by the compaction rollers. In the course of this research project a different asphalt beam sample preparation process using a rolling compaction was developed. This compacted and self contained beam sample compaction machine should improve the deficiencies of the static compaction process mentioned above.

Figure 12 and 13 show schematically the rolling compactor. The compactor consists of four basic components, the sliding motion assembly, the rolling wheel compactor, the operation control system and the beam sample mold. The main features of each of the components are presented in the following.

Sliding Motion Assembly

This assembly composed of a 15 in. wide by 24 in. long by 1 in thick steel plate attached with 4 heavy duty roller bearing at the bottom, The beam sample mold and the restraints are attached on the top of the plate. The sliding plate is attached to a double action hydraulic cylinder aligned horizontally at the bottom. When the horizontal hydraulic cylinder rod is

extended and retracted at a constant rate, it will cause the sliding plate and the beam samples secured on top of it to move back and forth reciprocating motions.

Rolling Wheel Compactor

The rolling wheel is to apply the vertical compaction load on the beam sample. The system consists of a load frame made of 4 threaded posts attached to a top and a bottom plate, a double action hydraulic cylinder attached to the top plate, and a roller attached to the cylinder rod. This rolling compactor is capable of applying up to 12000 lb of compaction load on the beam sample. Two horizontal restraining bars are installed between the roller clevis to restraint the horizontal movement of the roller due to the shear forces induced between the beam sample and the roller during the rolling compaction. This is needed to prevent excessive wear of the cylinder bearing.

Beam Sample Mold

Figure 14 shows schematically the beam sample mold assembly. It consists of a beam sample mold made of 0.25 in. thick steel plates and the constraints made of heavy steel angles. The constraints are bolted down on the sliding plate to confine the thin steel beam mold during the beam sample compaction. In the normal sample compaction operation, only one constraint needed to be removed to free the beam mold while the other constraint can be permanently attached to the sliding plate. This can simplify the beam sample compaction operation somewhat. This beam mold assembly can significantly ease the handling as compared with the cumbersomeness of handling the presently used heavy beam mold.

Hydraulic System and Operation Control

Figure 15 shows schematically the hydraulic system for controlling the horizontal sliding motion and the vertical loading. The horizontal reciprocating motion is controlled by the horizontal actuator with the speed adjustable by the flow valve. When this actuator is activated from an "ON-OFF" toggle switch, see Fig 16, the solenoid will causes the actuator to move horizontally in one direction. This will push (or pull) the sliding plat and cause the plate to slide at a constant speed in one direction (with the roller bearings roll along the rails) until the plate contacts a limiting switch positioned at the extreme end of the horizontal movement. When the limiting switch is activated by the contact, it will cause the solenoid to reverse the direction of the actuator. This causes the sliding plate to move at the reverse direction until it contacts the other limiting switch at the other extreme end of the traveling. Activation of this limiting switch again will cause the actuator to reverse the direction of the motion of the sliding plate. Thus the sliding plate will automatically slide back and forth with the range of the horizontal movement set by the two limiting switches and with the speed of the motion set by the flow control valve. This reciprocating motion will continue automatically while the ON-OFF switch remains at ON position and will stop when it is switched to "OFF" position.

The vertical loading is controlled by "UP" and "DOWN" switches on the control penal. When the "DOWN" switch is activated, the solenoid will cause the vertical actuator to applied a downward (push) motion and thus applied a vertical load on the beam sample via the roller wheel. The magnitude of the vertical load is manually controlled by a pressure regulator and is shown on the pressure gage, see Fig 16. During the sample compaction, the vertical compaction load will start at a low magnitude and

will be gradually increased to the desirable magnitude to achieve the beam density compaction requirement. At the end of the compaction, the applying pressure again will be reduced first and the "UP" button is then pushed to cause the actuator to retract.

The loading of the vertical actuator can be activated only when the horizontal sliding action is already activated. Anytime when the sliding action is stopped, the vertical actuator will automatically retracted. This will prevent the vertical load to press against the beam sample when the horizontal motion of the beam sample is accidentally stopped. The vertical actuator is also controlled by a vertical limiting switch so that when the beam sample has been compacted to the approximate desirable depth, this limiting switch will be activated and cause the actuator to retract. This will automatically stop the vertical actuator from overcompact the beam sample. There is a manual vertical loading button to allow for additional compaction. When this button is depressed, the actuator will again be lowered and continued to exert load on the beam sample for additional compaction.

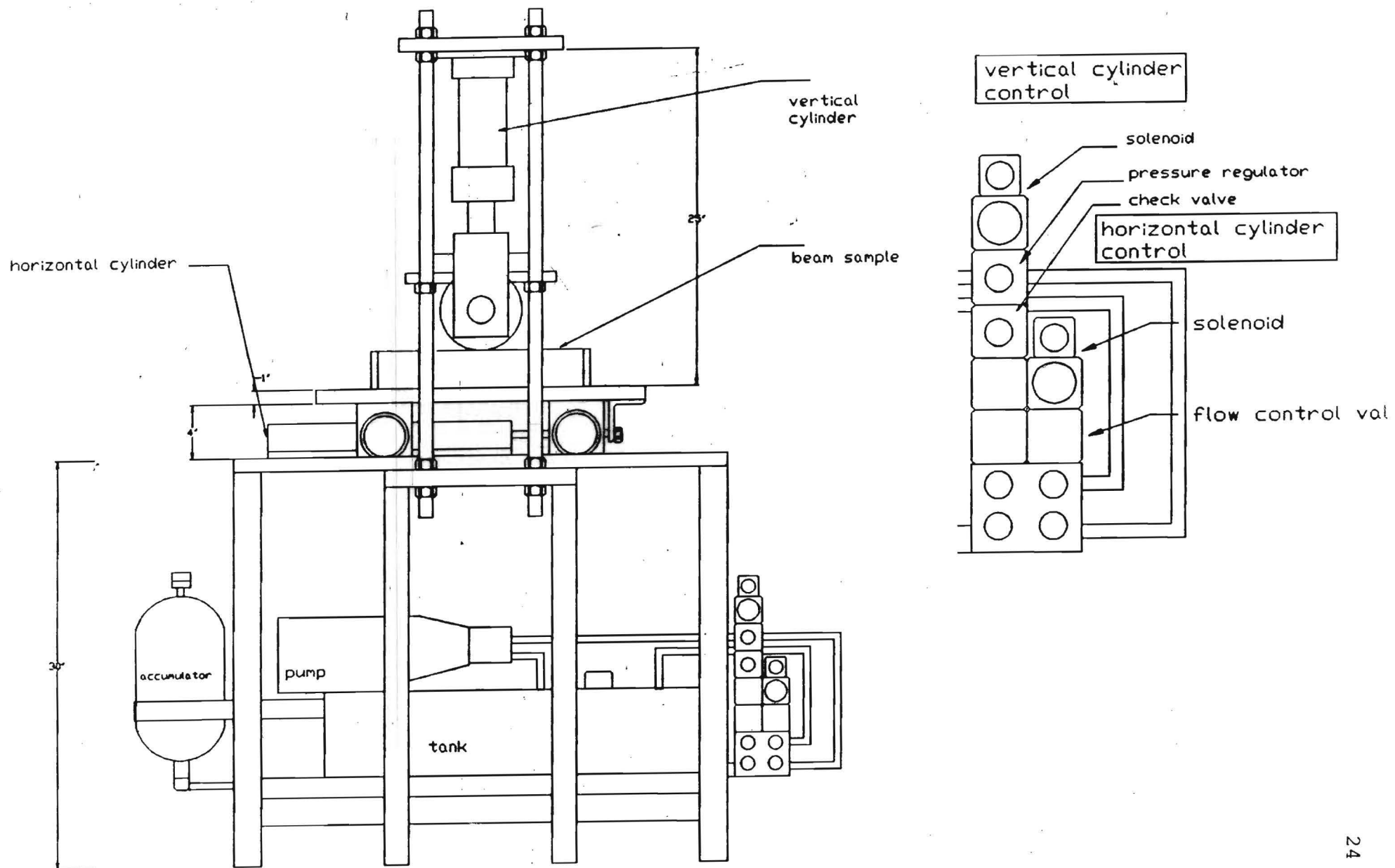


FIGURE 12 ROLLING COMPACTION MACHINE (FRONT)

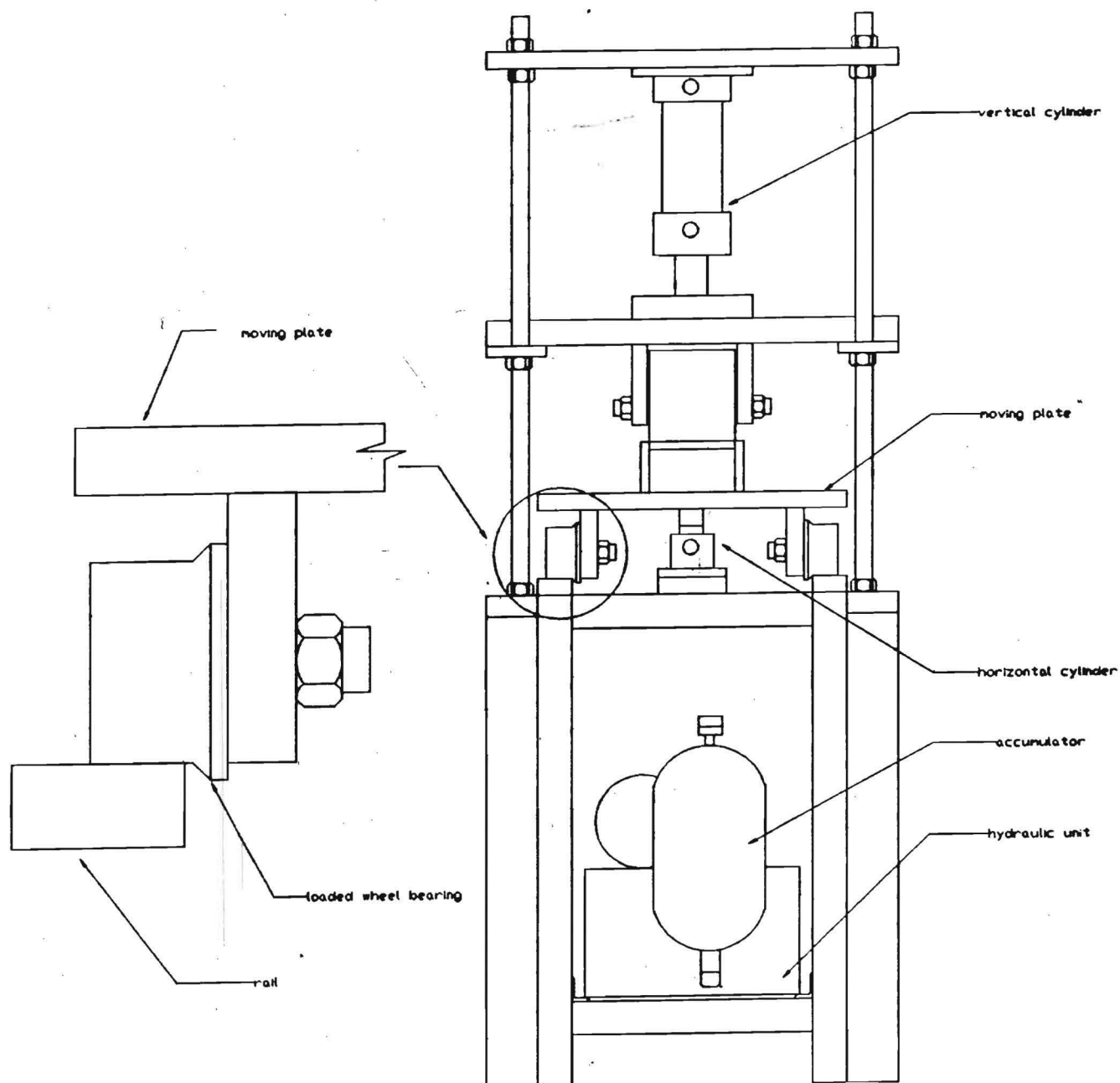


FIGURE 13 ROLLING COMPACTION MACHINE (SIDE)

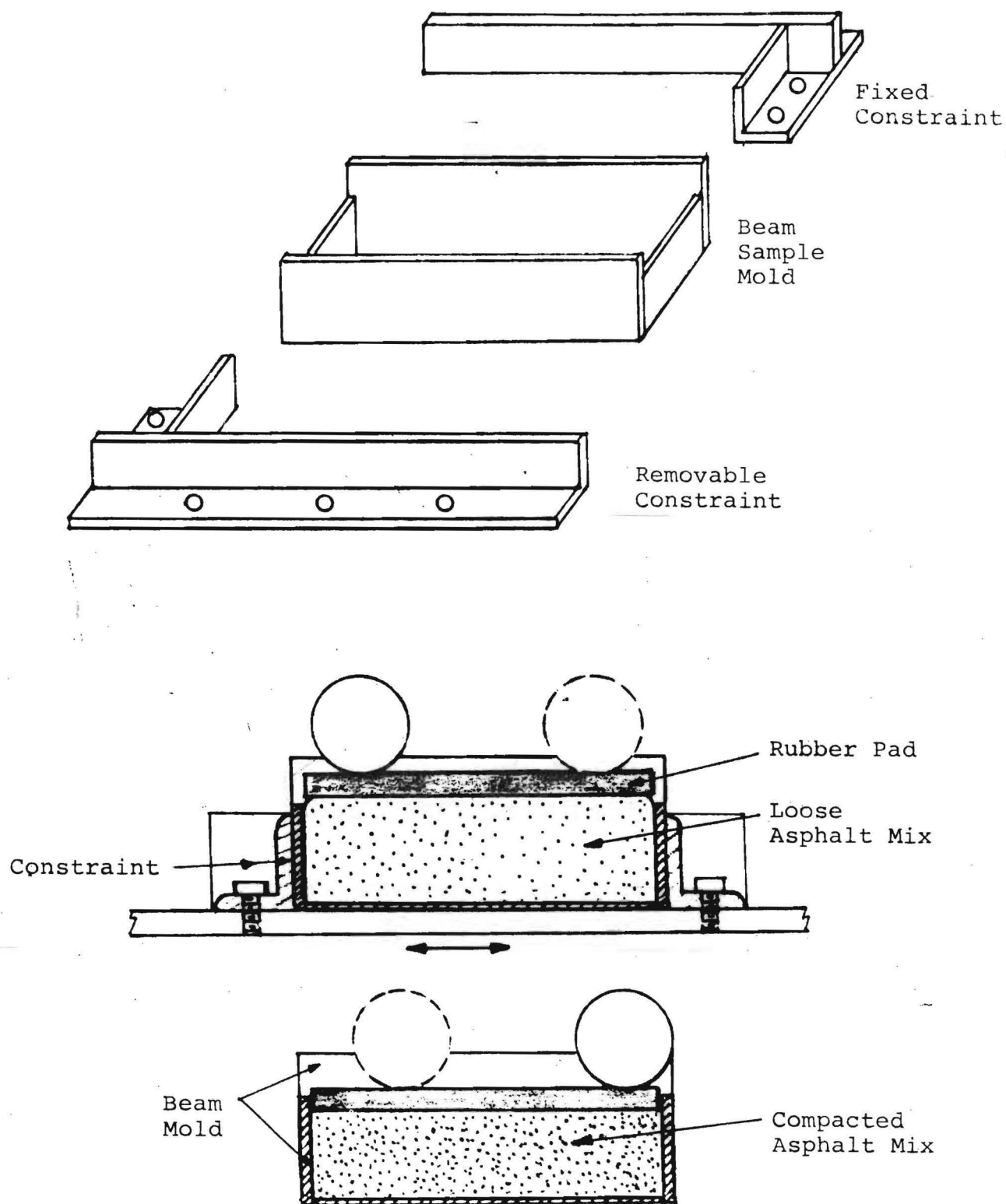


FIGURE 14 BEAM SAMPLE MOLD ASSEMBLY

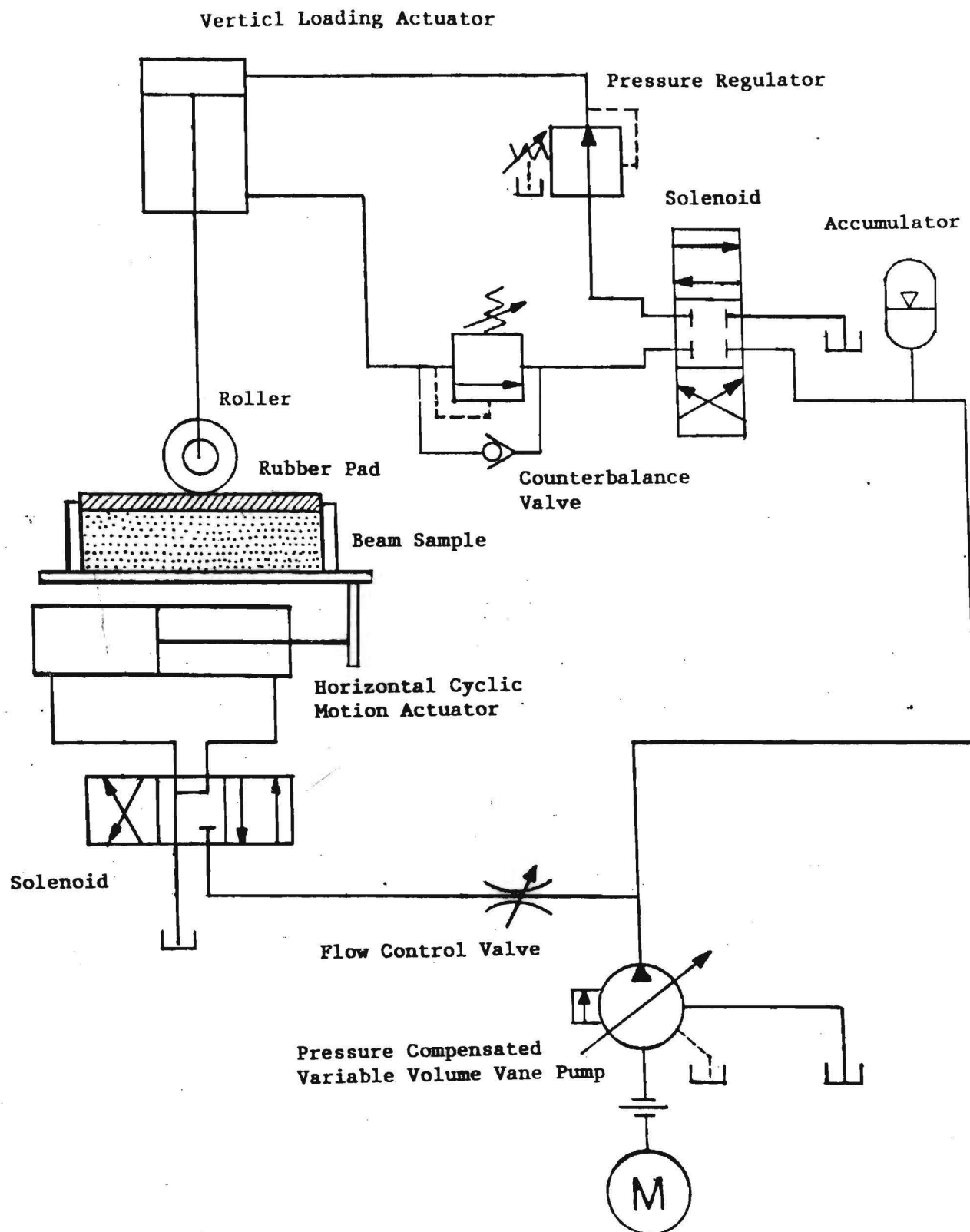


FIGURE 15 ROLLING COMPACTION HYDRAULIC SYSTEM CONTROL CIRCUIT

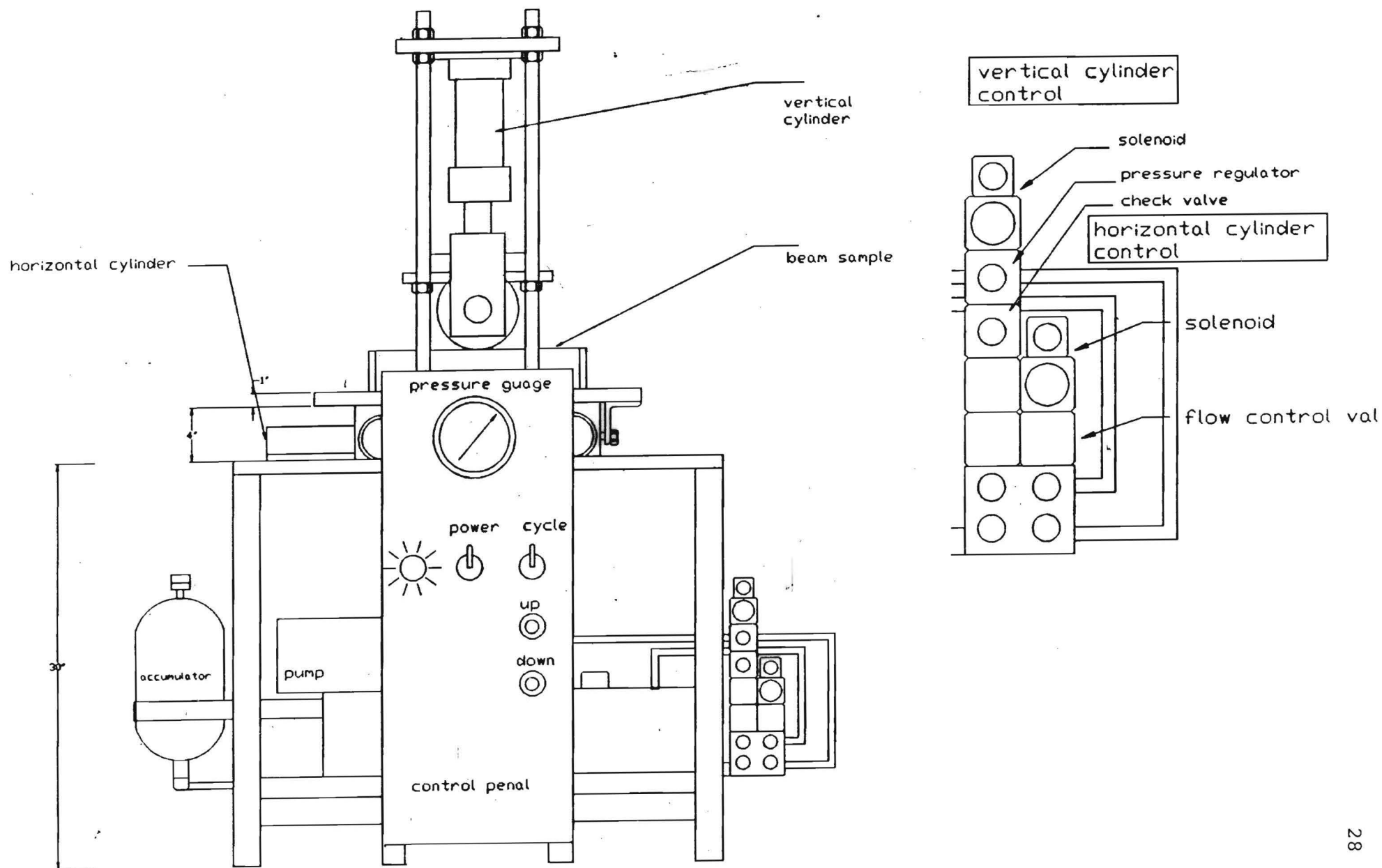


FIGURE 16 ROLLING COMPACTION MACHINE CONTROL PANEL

APPENDIX

APPENDIX A

Operation Procedure for Loaded Wheel Testing

A. Place and Secure Beam Samples

1. Open the front door and pull the beam sample holding plate partially out. Be careful not to pull the plate too far out, the plate may tip. Use the sliding plate position adjusting button on the control panel to position the sample holding plate right at the front door.
2. Place the first beam sample on the beam sample holding plate against the back side restraining bracket and the left end restraining bracket, tighten the right end restraining angle bracket against the right end of the specimen. Note that the back side and the left end restraining brackets are normally bolted down on the beam sample holding plate and need not be loosen or removed when replacing the beam samples. Place the U-shaped side restraining bracket firmly against the front side of the first beam sample. This bracket does not need to be bolted down.
3. Place the second beam sample against the U-shaped bracket and the left end restraining bracket, and tighten the right end restraining angle bracket.
4. Repeat the same procedure for setting up the third beam sample. The front side of the third beam sample is confined by an angle bracket. This bracket should be bolted down on the beam sample holding plate.
5. With all three beam samples properly secured, measure the initial beam surface profile using the rut depth measurement stand and the electronic indicator. The procedure for making the measurement is described in C-2 in the following.
6. After that, push the beam sample holding plate back and secure it on the sliding plate and close the front door.

B. Starting Loaded Wheel Testing

1. Set the "PREDETERMINING COUNTER" to the number of repetitions for the test to be run.
2. Reset the "TOTALIZING COUNTER" to zero, if needed.

3. Check the chamber temperature to ensure that temperature in the beam samples has been stabilized and at the testing temperature.
4. Check the pressure gage reading for the pressure in the hoses. Use the pressure regulator directly under the pressure gage to adjust the pressure, if needed.
5. Check the pressure gage reading for the pressure to be applied by the air cylinders. The calibration chart between the pressure reading and the load applied by the air cylinders is posted on the right side of the control box. Use the pressure regulator directly under the pressure gage to adjust the pressure, if needed. Check the ball valves directly above each cylinder which should be at the open position (pointing horizontally).
6. Switch the "LOAD" toggle switch to "ON" position. This will immediately cause the loading wheel to lower down and exert the preset load on the pressurized hose. After about 2 seconds delay, the reciprocating motion will start.
7. The test will continue until the preset number of repetitions has been completed and the "PREDETERMINING COUNTER" has counted down to zero. At this point, the test will be automatically terminated. The loaded wheel will retract; the reciprocating motion will stop and a red indicating light will be on. The number of repetitions during this test period should be indicated on the "TOTALIZING COUNTER".

C. Rut Depth Measurement

1. Open the front door to expose the beam samples. Use the sliding plate position adjusting button on the control panel to adjust the sliding plate position so that the beam sample holding plate can be pulled out from the front door. Loosen the latch and partially pull out the sample holding plate to expose the beam samples between the rubber hoses.
2. Place the rut depth measurement stand over the beam sample, and set the stand on the sample side constraints with the protruded section of the stand fit into the notch on the side constraint. Place the electronic indicator into the slots with its base rest firmly on the groove over the slot and slide the indicator along the groove to detect the maximum rut reading on the indicator. This maximum rut reading represent the deepest depression of the beam sample at this particular position. Record the reading. Proceed to the next slot and use the same process to obtain the max. rut reading at this slot position. After five rut readings have been taken from one beam sample, proceed to the next beam sample and do the same.

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FINAL REPORT

**Development of a New Loaded Wheel Testing Machine
for Evaluating Rutting of Asphalt Mixes**

by

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State of Georgia

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EXECUTIVE SUMMARY

Development of a New Loaded Wheel Testing Machine for Evaluating Rutting of Asphalt Mixes

The objective of this proposed research project was to develop a semi-automatic loaded wheel testing machine and a rolling compaction machine which incorporated various improvement ideas suggested by various current users. The following summarize the improvement features of these two machines.

LOADED WHEEL TESTER

- (1) The loaded wheel testing can be semi-automatically controlled. By presetting the number of repetitions, the test will run and stop when the preset number of repetitions is reached.
- (2) The machine is able to test three 5 in wide beam samples simultaneously.
- (3) The machine is capable to test a 18 in. wide slab sample.
- (4) The machine has the option of testing samples under water.
- (5) Temperature control is more accurate and consistent and can be adjustable to 140 °F.
- (6) The machine can also used to preheat 3 beam samples during normal testing.
- (7) The tire or hose pressure and the magnitude of the wheel load can be adjusted to higher level.
- (8) A digital indicator is used for rut profile measurements. The indicator is capable of interfacing with a computer.

ROLLING COMPACTION MACHINE

- (1) The machine is relatively compact and self contained.
- (2) Beam sample compaction simulates the rolling action of a roller.
- (3) Beam sample preparation is easier and more consistent beam density can be obtained.

These two machines developed from this project are easy to use, can generate more reliable results and are suitable as a routine asphalt testing facility for evaluating rutting characteristics of asphalt mixes.

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CHAPTER 1 INTRODUCTION

~~Rutting~~ of asphalt pavements has a major impact on pavement performance. Rutting reduces the useful service life of the pavement and, by affecting vehicle handling characteristics, creates serious hazards for highway users. This excessive rutting in asphalt pavements becomes a major concern in many parts of the United States due to the ever-increase in magnitude and in number of repetitions of the axle loads. The use of radial tires which develop high tire pressure also contributes to the serious rutting problem.

Marshall mix design method and Hveem mix design method are two commonly used methods for the design of asphalt mixes. Although asphalt mixes designed by these two methods most likely can eliminate extremely unstable mixes, there is no assurance that an asphalt mix satisfying the design criteria of either one of these methods will not develop unacceptable rutting under normal traffic conditions. Thus, there is increased interest in developing mixture evaluation procedures which will be more responsive and can better assess the rutting characteristics of asphalt mixes. A recent report from the Strategic Highway Research Program (SHRP-A/IR-91-104 Summary Report on Permanent Deformation in Asphalt Concrete, by Sousa, Craus and Monismith) described various laboratory test methods for permanent deformation evaluation. Unfortunately most of the methods lack the field verifications.

Recognizing the need to have a simple testing procedure which can be used to supplement the current Marshall mix procedures for obtaining asphalt mixes with better rutting resistance, Dr. Lai of Georgia Tech,

working closely with the GaDOT, has developed a wheel tracking machine (Loaded Wheel Tester, LWT) and the testing procedure for evaluating the rutting characteristics of asphalt mixes. The initial version of the LWT has been used extensively for five years by GaDOT. The results have demonstrated good field verifications. In 1990 the Federal Highway Administration, Office of Technology Applications sponsored a round-robin testing program, participated in by six state highway departments, to evaluate and verify the applicability of this testing method. Judging from the laboratory and the field verification results, it has shown that using the loaded wheel testing as a supplement to the Marshall mix design can provide a simple, practical and yet accurate means of evaluating the rutting characteristics of asphalt mixes.

When the LWT program was originally developed, the emphasis was primarily to evaluate the applicability of the concept rather than the refinement of the machine itself. It was recognized then that the machine would have to be modified if and when the LWT testing concept has proven to be viable. With the concept of the LWT testing has proven to be viable, and the testing has been used extensively by GaDOT and by several other State DOT's in the past several years, it is desirable to modify the LWT machine to improve the operational characteristics and make it more suitable for use as a routine laboratory test apparatus. An interim research study sponsored by Georgia DOT to assess the various desirable improvement ideas has been completed. The ideas developed in that study became the basis for this proposed research project for developing a new loaded wheel tester for evaluating the rutting characteristics of asphalt mixes and a rolling compaction machine for preparing the asphalt beam samples which can better simulating the rolling action of a roller.

CHAPTER 2 OF LOADED WHEEL TESTER

In the original proposal for this research project, several improvement features for this new loaded wheel tester were listed along with the schemes to implement these improvement features. The original improvement ideas were further refined in the course of design and fabricate the new loaded wheel tester. The following are the improved features of the new loaded wheel tester over the current version.

- (1) The loaded wheel testing can be semi-automatically controlled. By presetting the number of repetitions, the test will run and stop when the preset number of repetitions is reached.
- (2) The machine is able to test three 5 in wide beam samples simultaneously.
- (3) The machine is capable to test a slab sample up to 18 in. wide.
- (4) The machine has the option of testing samples under water saturated condition.
- (5) Temperature control is more accurate and consistent and can be adjustable to 140 °F.
- (6) The machine can also used to preheat 3 beam samples during normal testing.
- (7) The tire or hose pressure and the magnitude of the wheel load can be adjusted.
- (8) A digital indicator is used for rut profile measurements. The indicator is capable of interfacing with a computer.

The new LWT machine consists of the following four components:

- A. Wheel tracking system
- B. Loading system
- C. Rutting measurement system
- D. Operation and temperature control system

The new LWT as shown in Fig. 1 has the overall dimensions of 56 in. long by 35 in. wide by 43 in. height (53 in. including the height of the air cylinders). Gross weight of the machine is approximately 1200 lbs. Details of each components of the machine are presented in the following.

(A) Wheel Tracking System

The wheel tracking system is shown schematically in Fig. 2 and 3 (shaded areas). The figures show that three 5 in. wide beams can be simultaneously driven by a common reciprocating driving assembly, which consists of a motor, a gear reducing box and a specially designed cam system. The reciprocating driving assembly drives the sliding plate assembly (Fig. 4) which rolls back and forth along two tracks. The top of the sliding plate holds three rubber hoses at the positions directly under the loading wheels. The beam sample holder plate (Fig. 5 and 6) which holds the asphalt beam samples and the beam sample constraints is placed directly on top of the sliding plate and is secured during the testing. The beam sample holder plate and the beam samples secured on top of it can be pulled out transverse to the direction of the reciprocating motion. This allows an easy access for placing the beam samples during the set up and for taking rut depth measurements on the beam samples after the testing.

(B) Loading System

Loading applied on the beam samples is by means of three pneumatic cylinders (Fig. 7,8 and 9). Each cylinder is attached with an aluminum wheel with its concave surface rolled on the pressurized rubber hose. Figure 10 shows schematically the loading control circuit. The magnitude of the wheel load applied on each beam sample is generated by a pneumatic cylinder which is regulated by a pressure regulator. Each cylinder is controlled separately by a ball valve thus allowing pressure in each cylinder to be turned off independently. Pressure in three rubber hoses is regulated by a common pressure regulator, so that pressure in three hoses will always be the same.

(C) Rutting Measurement System

Figure 11 shows the rut depth measurement device. the system consists of a measurement stand and a electronic indicator. The measurement stand has 5 slots at 2 inches apart. The base of the stand sits on top of the beam sample lateral constraints and has a protruded section which fits into a notch on the top of the lateral constraints. This arrangement ensures that the measurement stand can always be placed at the same position with respect to the beam sample. The electronic indicator has the sensitivity of 0.0005 in. or 0.01 mm. The operation of the indicator is virtually identical to that of a mechanical dial gage. This electronic indicator has several additional features and can be directly connected to a processor for storage, process and printout the data. The processor also serves as the interface with a host computer via RS-232 cable.

(D) Operation and Temperature Control

The entire machine except the motor and the gear reducer is enclosed in a environmental chamber, see Fig. 1. The environmental chamber made of insulation panels with aluminum skin insulated inside with 3/4 in. rigid foam insulation board. Each insulation penal is attached to the steel frame and can be individually detached for easy access to the interior of the machine. The front penal has a hinged door with a viewing window. This door is used to access to the beam sample holding plate for reaching the beam samples during the set up and for the rut depth measurements.

All the heating elements and the temperature circulation and control are attached on the inside of the back and the right panels, see Fig 12. Temperature in the chamber can be set and regulated by a thermostat, see Fig.7. In addition, a separate temperature indicator with a temperature prob inserted into a dummy asphalt beam sample allows temperature in the asphalt samples to be monitored. It has determined that this environment chamber can maintain the temperature up 140 °F with a 2 °F fluctuation.

All the controls for operating the loaded wheel test are mounted on the control box on top of the machine, see Fig. 1 and Fig. 13. The main feature of the operation control is to control the start-stop of the loaded wheel testing. Before the loaded wheel test is to be started, the following steps should be taken.

- (1) The samples should be properly secured on the beam sample holding plate.
- (2) Temperature in the beam samples should have been stabilized to the test temperature.
- (3) Pressure in the hose is in the preset value (adjustable via the pressure regulator) and the pressure gage for the air cylinders has indicated the correct pressure reading.
- (4) The preset counter has been reset to the desirable number of repetitions.

With all of these properly check out, the test "ON/OFF" toggle switch is then turned to "ON" position. This will immediately cause the air cylinders to extend and exert a predetermined magnitude of load on the rubber hoses. After 2 seconds delay, the motor will be turned on and start the reciprocating actions. Each time the sliding plate reaches one end, it touches the limiting switch (see Fig.7). This causes the preset counter to count down one on the counter and also causes the totalizing counter to add one on the counter. When the preset counter reaches zero it will simultaneously invoke the following three actions, release pressure in the air cylinders and retract the loading wheels, stop the motor and the reciprocating motion of the sliding plate, and turn on the red light to indicate the termination of the test.

On the control panel there is a bush-bottom for adjusting sliding plate stop position. Upon open the door, this push bottom switch can be momentarily depressed to manually adjust the position of the sliding plate so that the beam sample holding plate can be positioned at the door. Upon release the latch, the beam sample holding plate can be pulled out partially while the sliding plate remains stationary. This will expose the beam sample rutting path from directly under the rubber hoses and allows the rut depth measurements to be taken, see Fig 11. If the test is to be continued, then the beam sample holding plate is push back to the secure position, close the door and reset the preset counter to the next desirable number of repetitions and restart the loading process. Or if the test is to be terminated, then remove the beam sample constraints and the beam samples in proper sequence.

There is a load calibration switch on the control panel. When this switch is turned to calibration position, it disables all other functions

associated with the normal testing and allows individual air cylinder to be calibrated. Calibrations were made for each cylinder. It was found during the calibration process that the responses among three cylinders under different pressures are virtually the same. The calibration chart between the pressure readings and the loads generated by the cylinders is posted on the right side of the control box. The heating switch on the control panel is to activate the heating and the thermostat for conditioning the environmental chamber temperature.

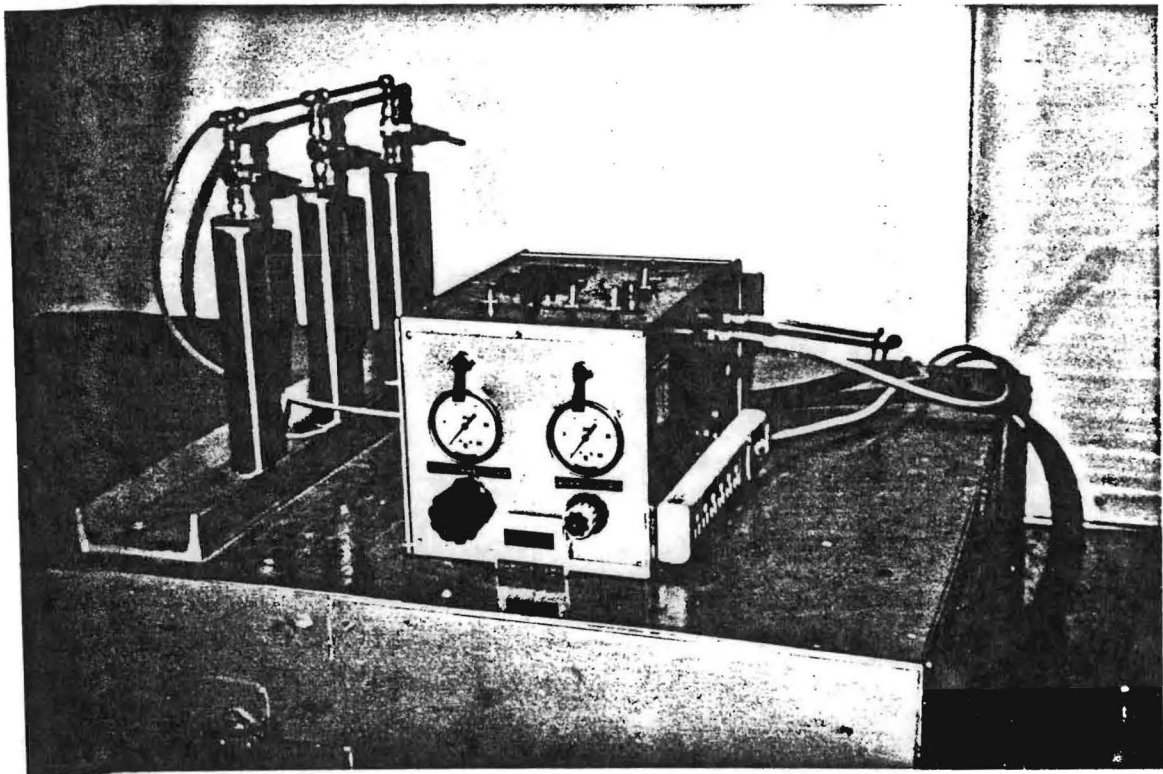
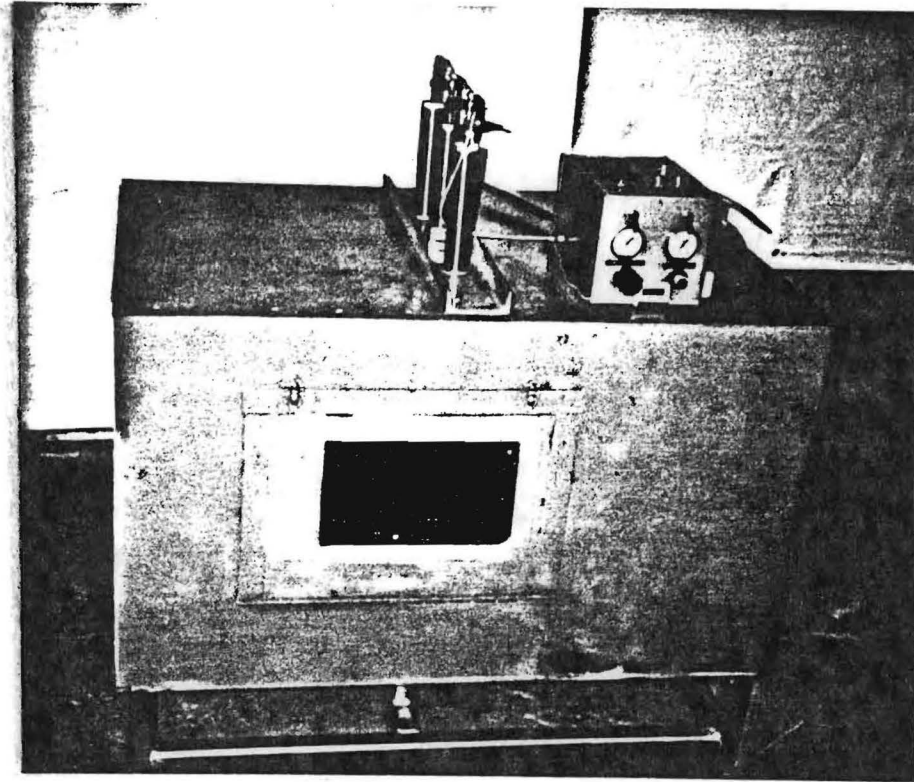


FIGURE 1. LOADED WHEEL TESTER

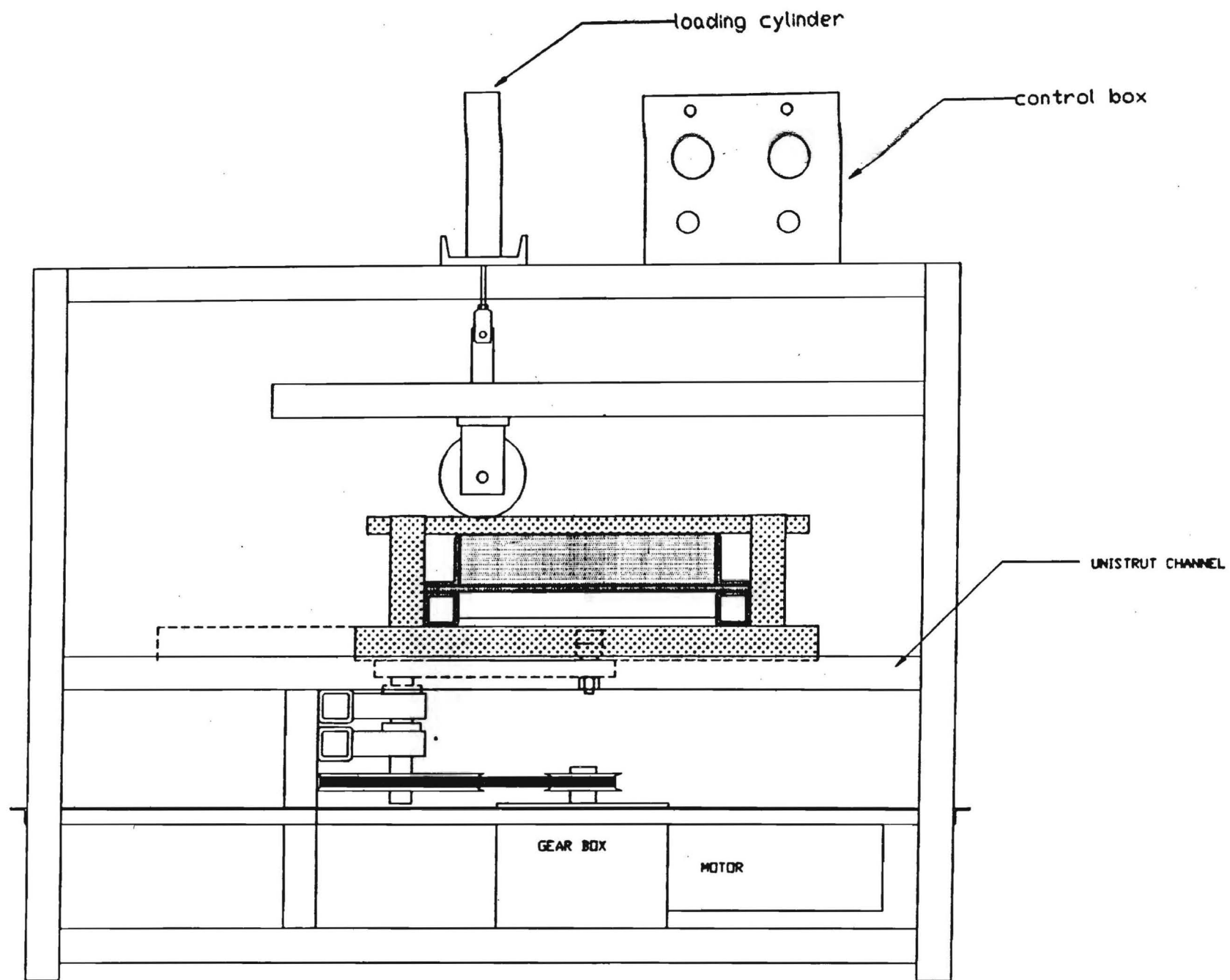


FIGURE 2 LOADED WHEEL TESTER WHEEL TRACKING SYSTEM (FRONT)

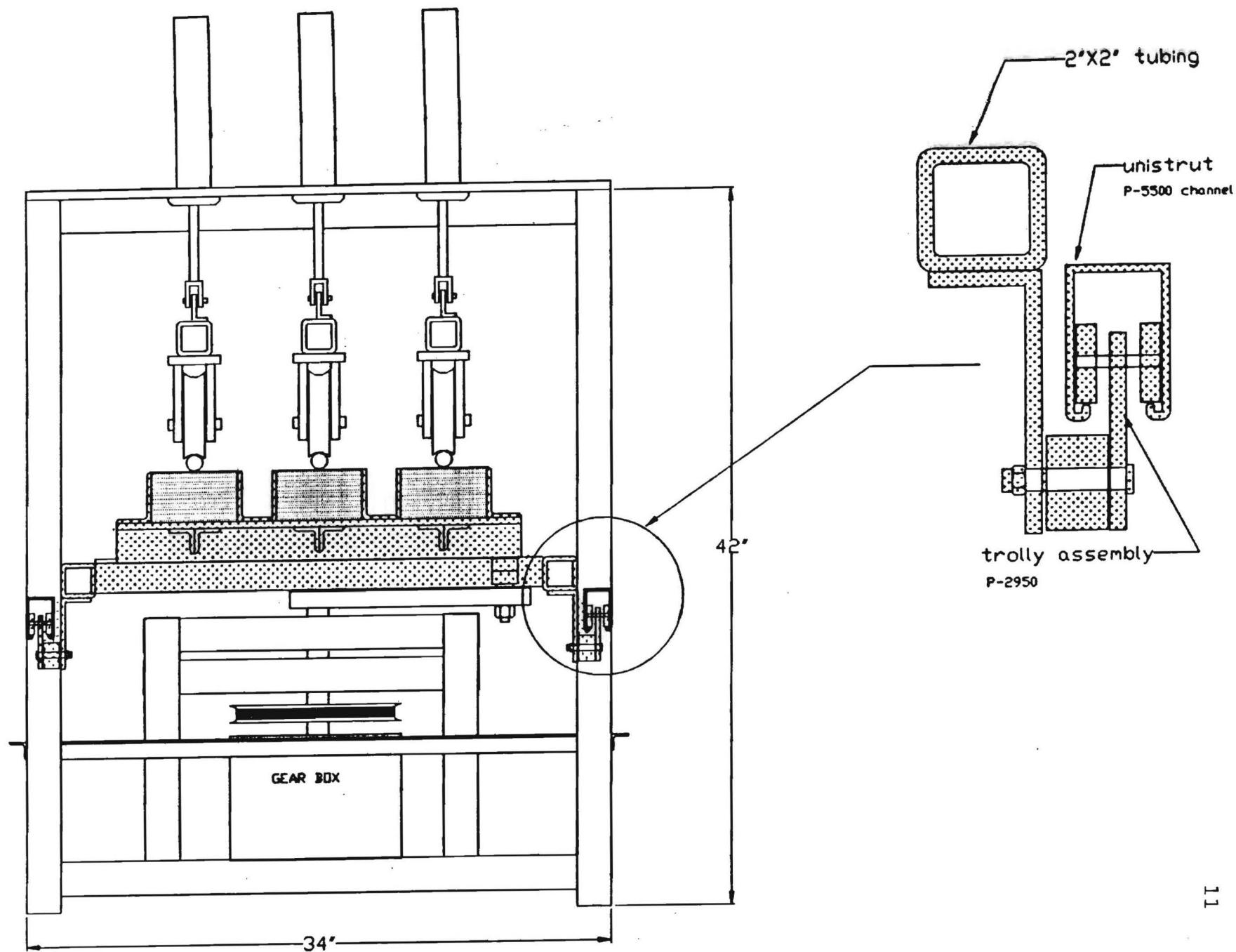


FIGURE 3 LOADED WHEEL TESTER WHEEL TRACKING SYSTEM (SIDE)

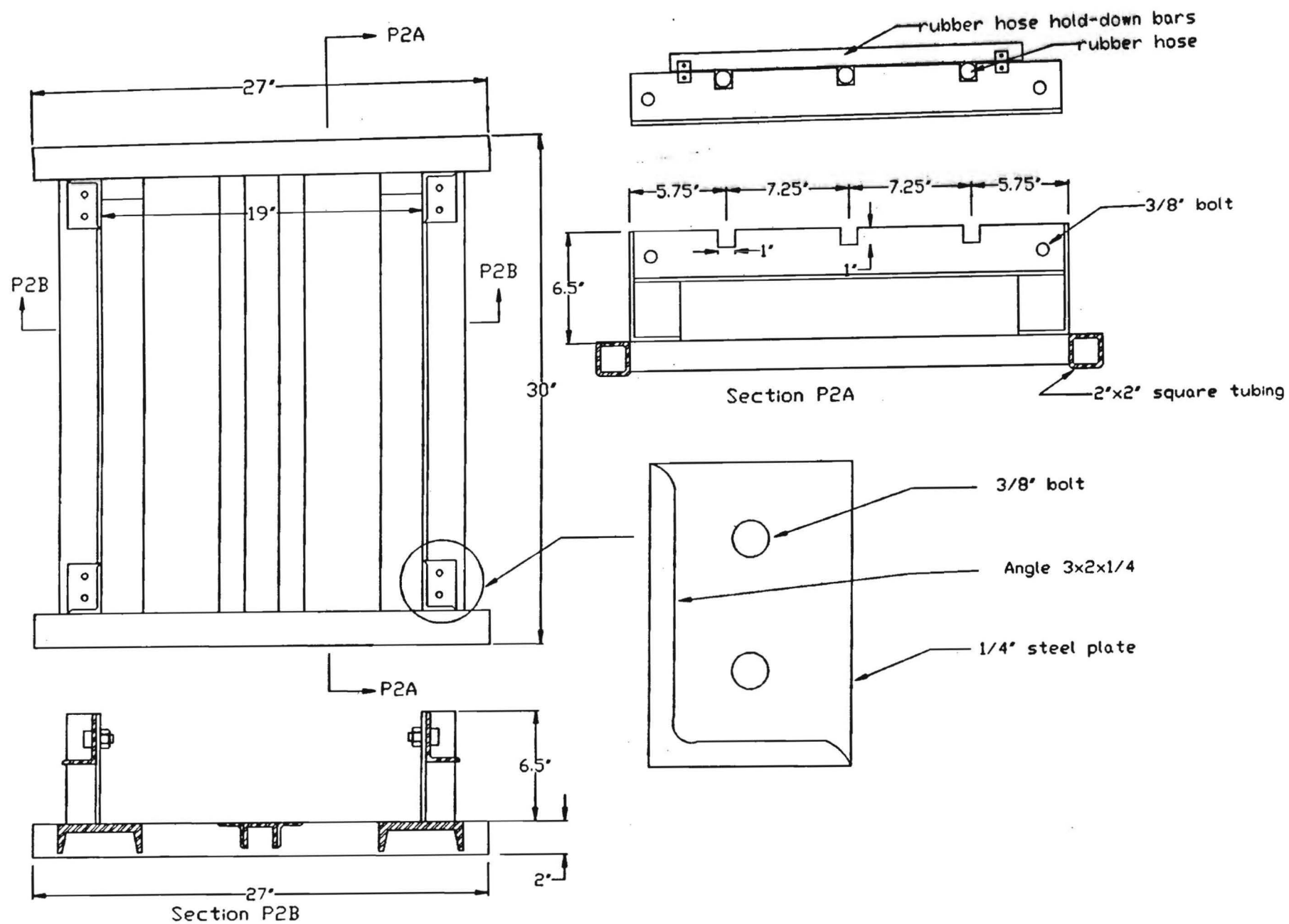
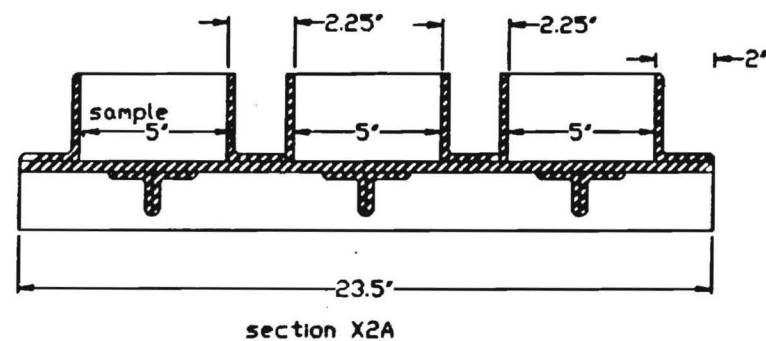
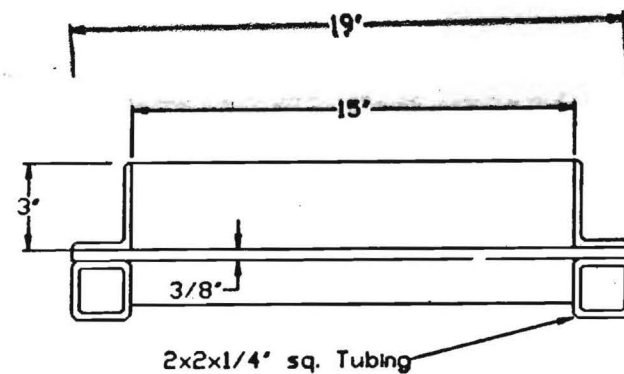
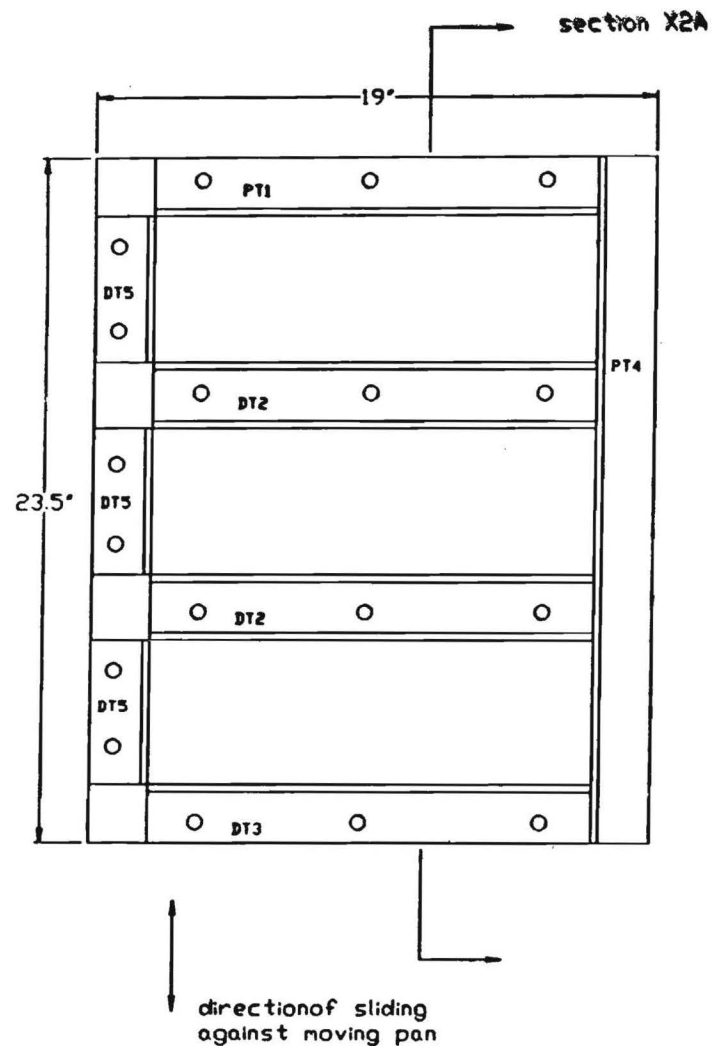


FIGURE 4 SLIDING PLATE ASSEMBLY



NOTE:

Sample tray is placed and secured on top of the moving pan. It can be pulled out to facilitate installation and removal of beam samples, and for rut depth measurements.

FIGURE 5 BEAM SAMPLE HOLDING PLATE

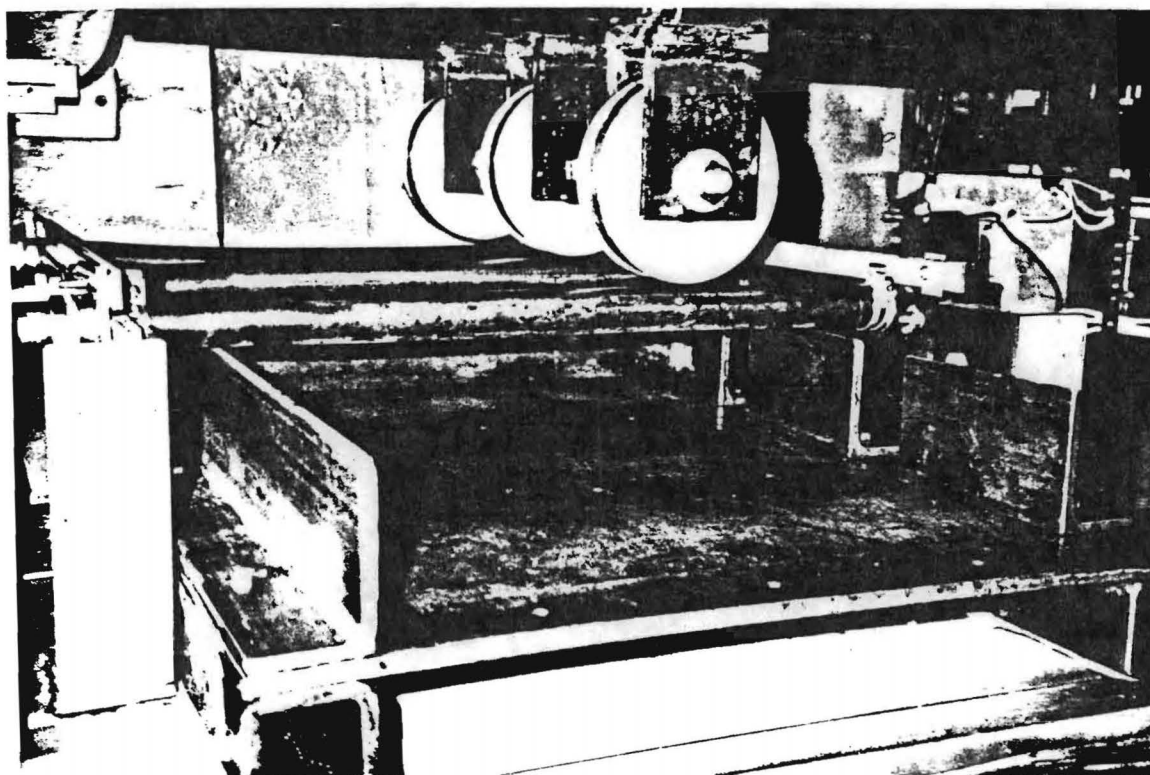
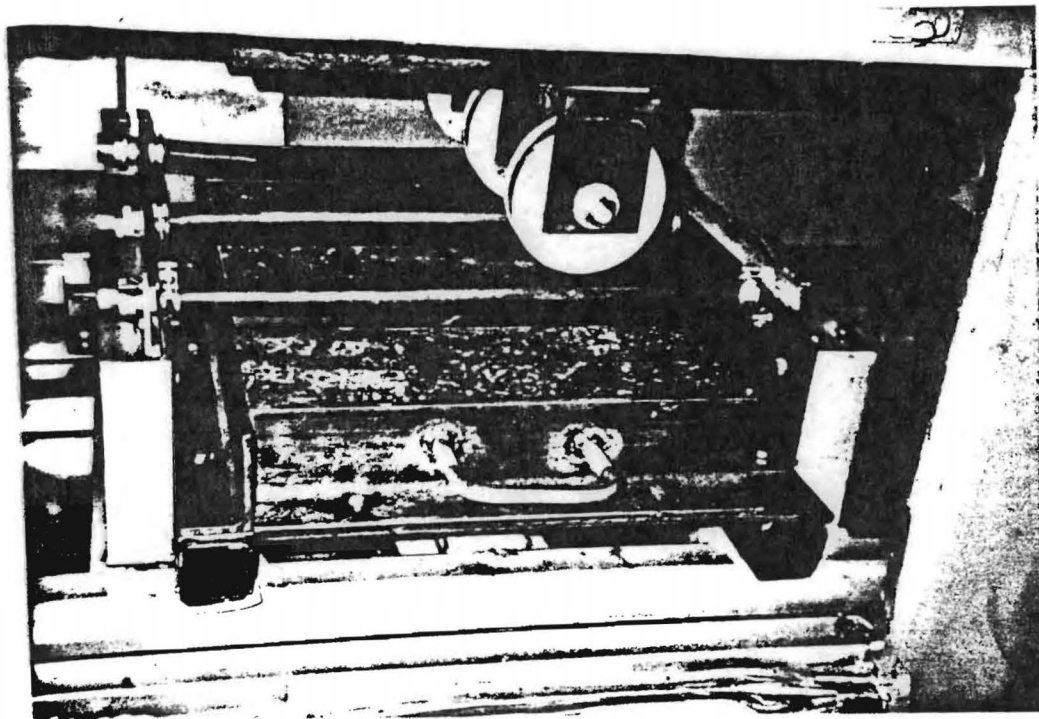


FIGURE 6 BEAM SAMPLE HOLDING PLATE (PHOTO)

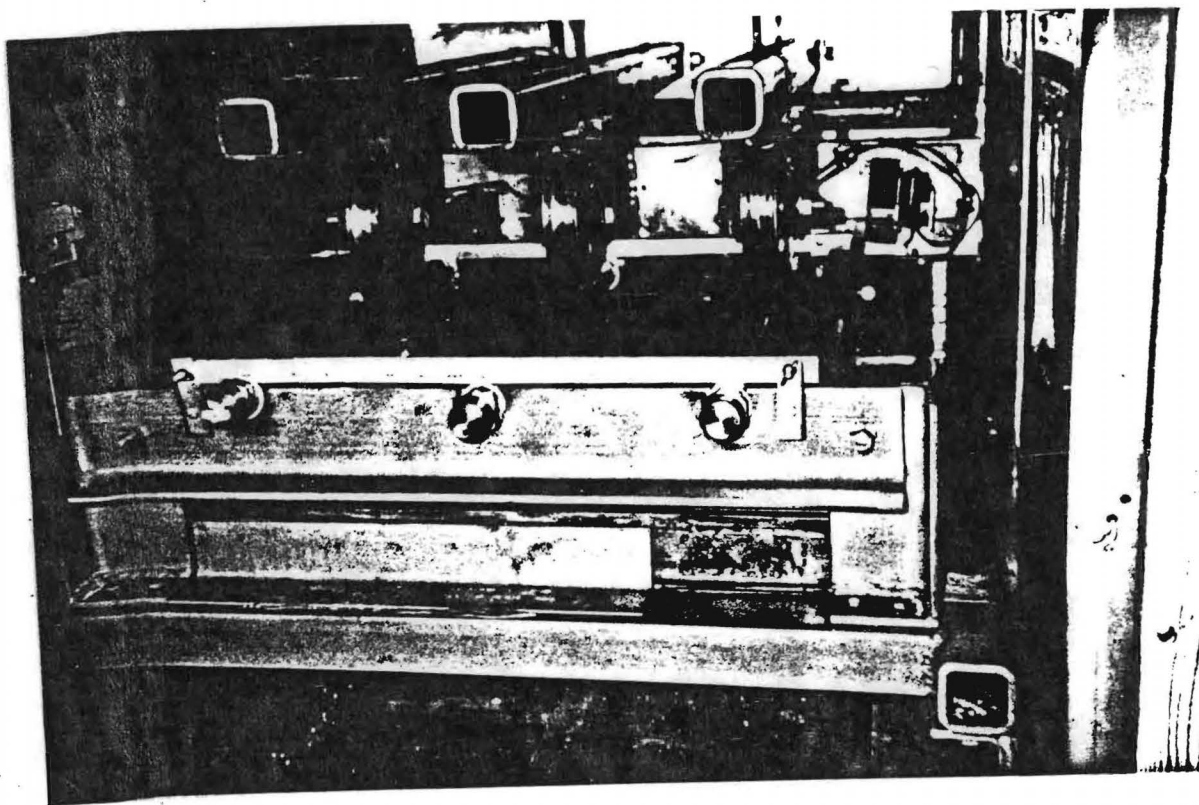


FIGURE 7 LOADING SYSTEM (PHOTO)

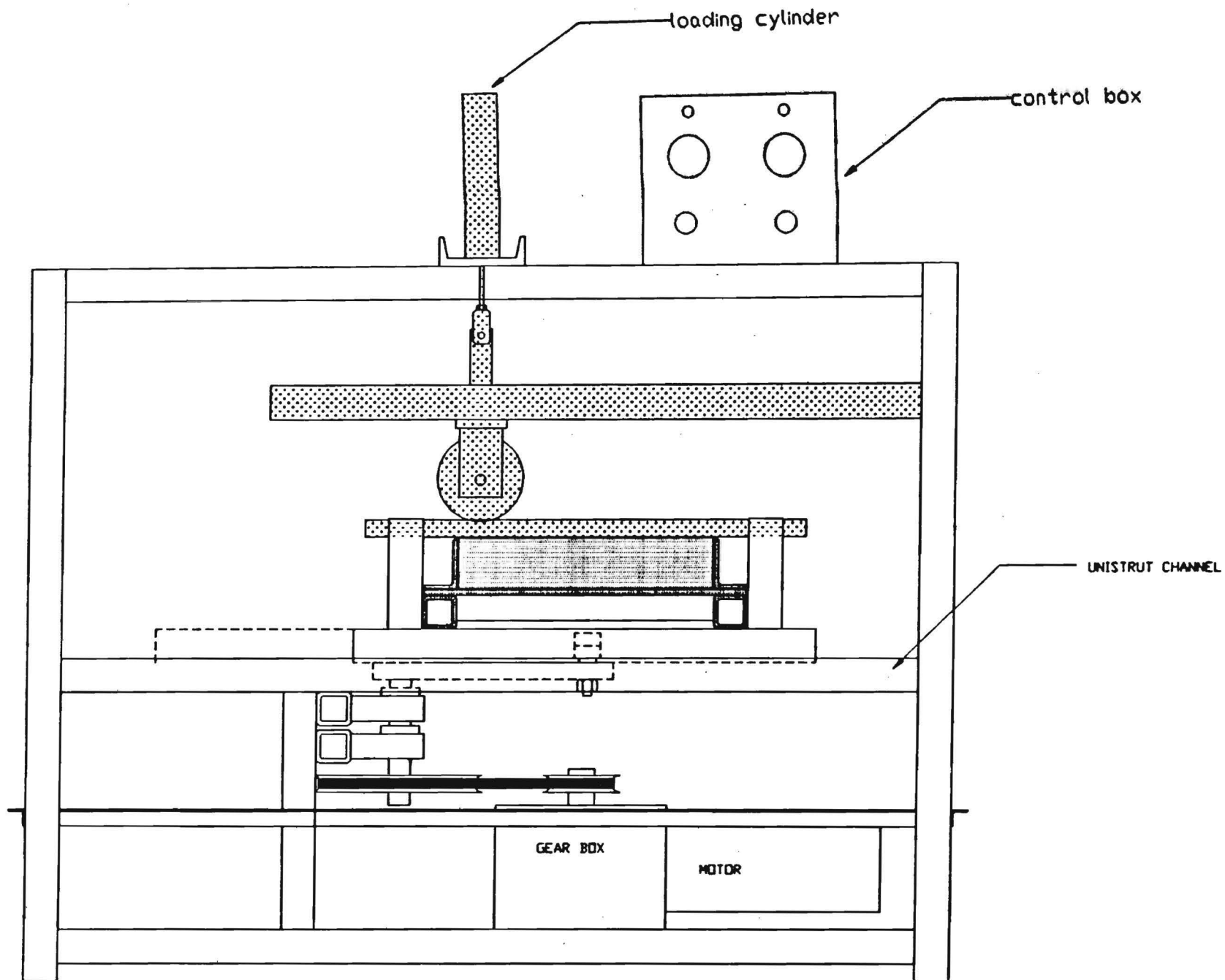


FIGURE 8 LOADED WHEEL TESTER LOADING SYSTEM (FRONT)

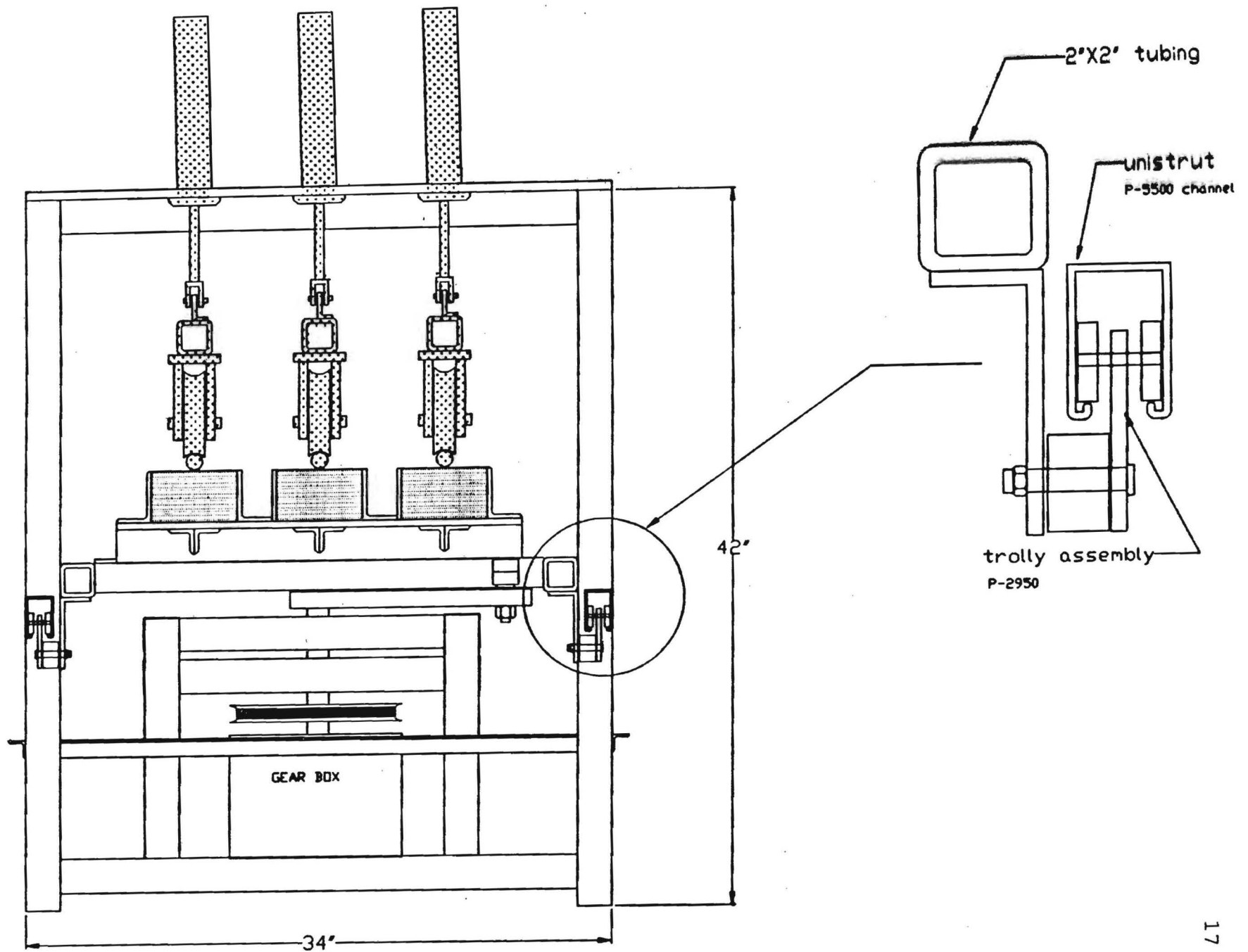


FIGURE 9 LOADED WHEEL TESTER LOADING SYSTEM (SIDE)

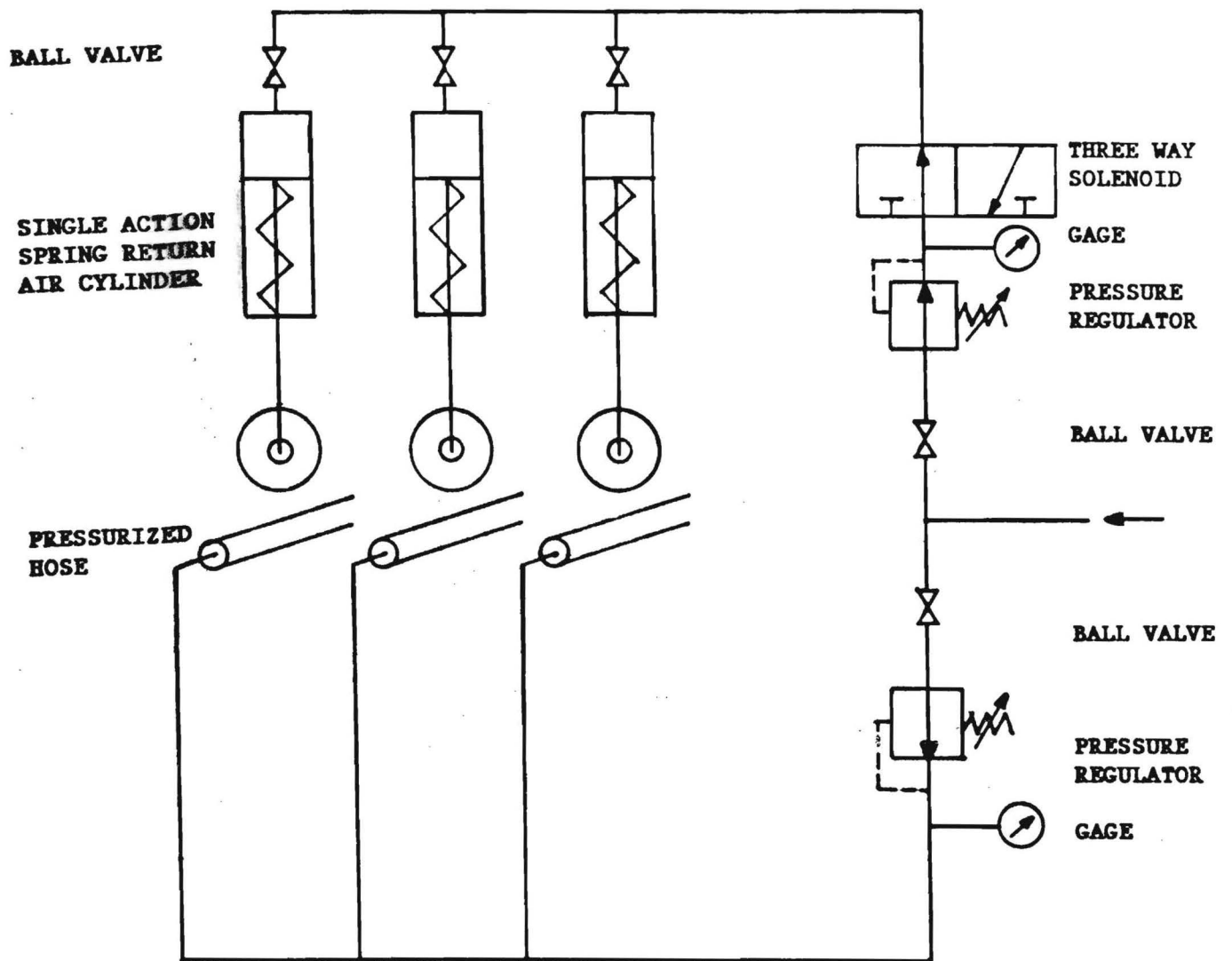


FIGURE 10 LOADED WHEEL TESTER LOADING CONTROL CIRCUIT

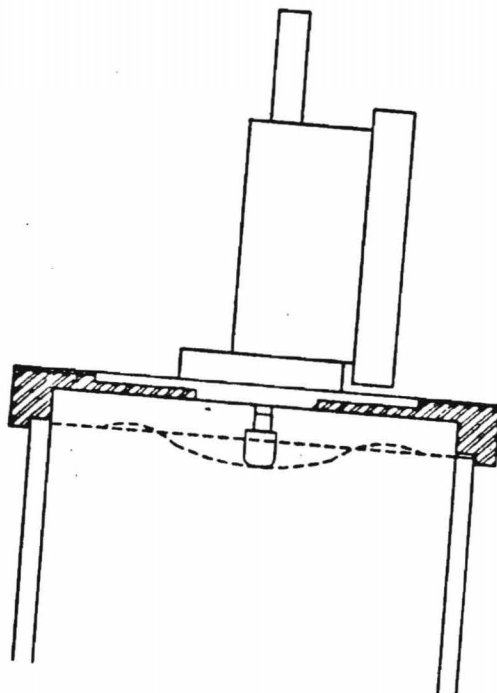
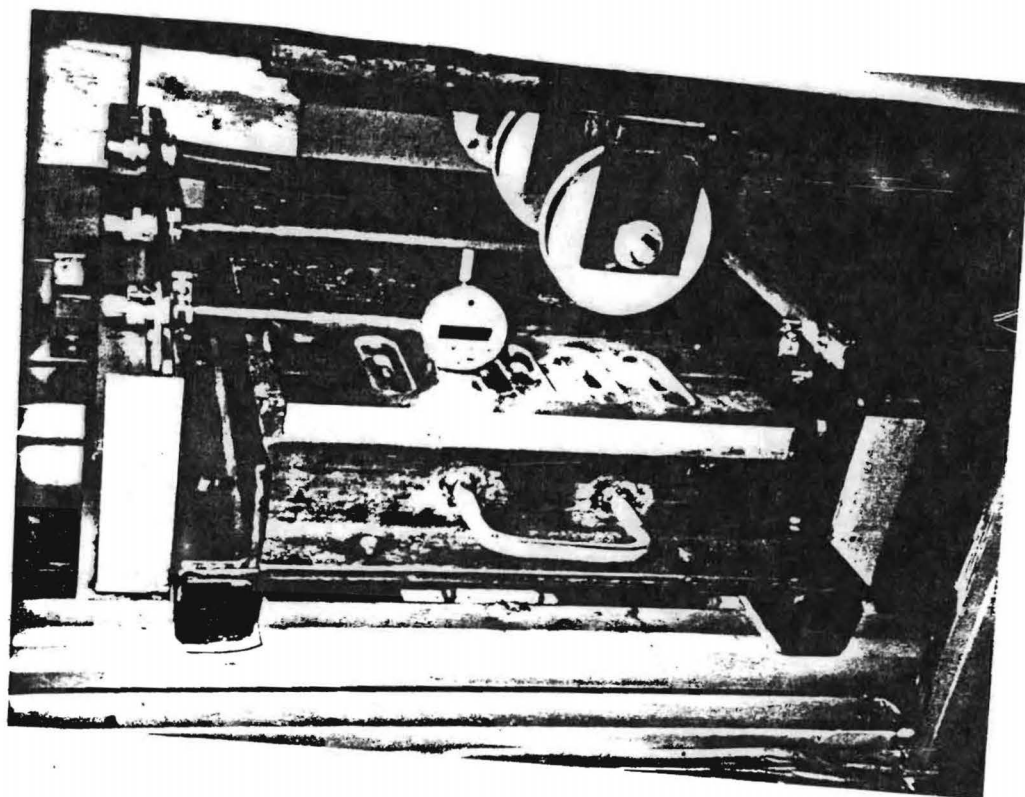
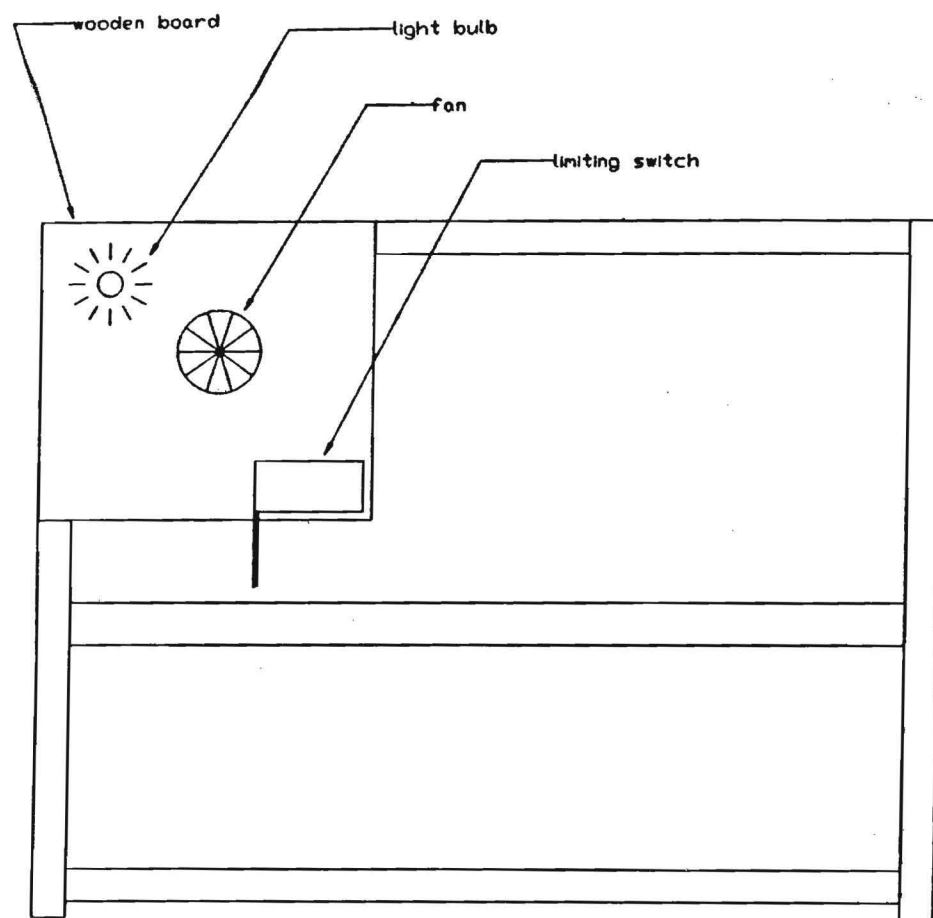
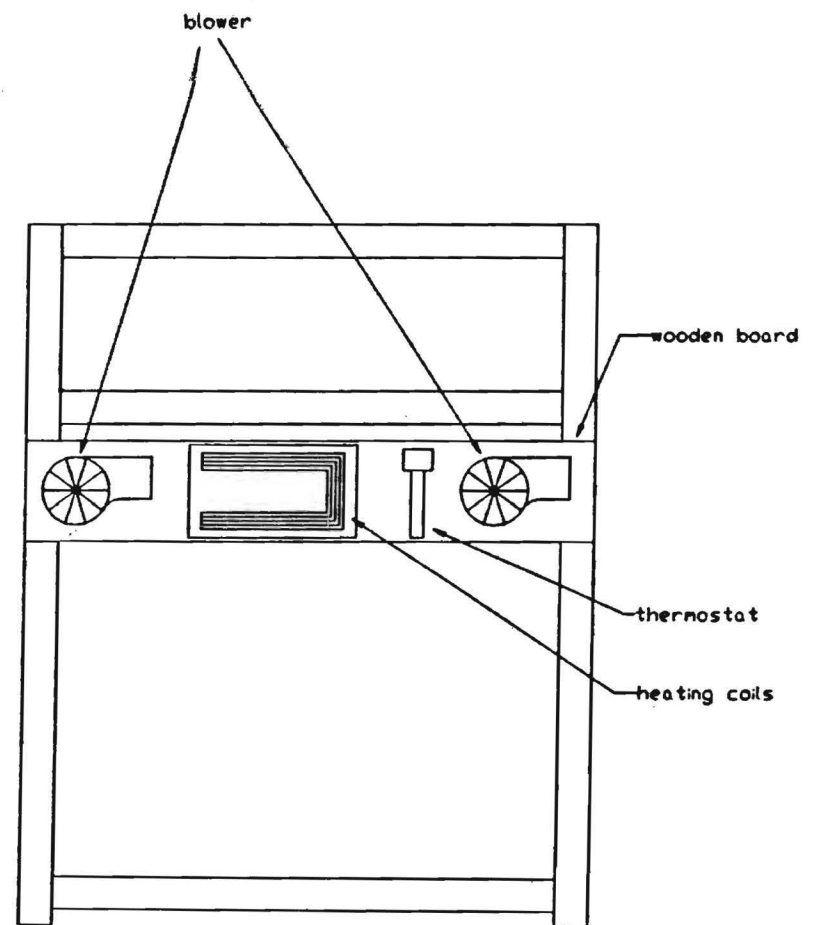


FIGURE 11 RUT DEPTH MEASUREMENT DEVICE



back panel



right panel

FIGURE 12 ENVIRONMENTAL CHAMBER TEMPERATURE CONTROL ARRANGEMENT

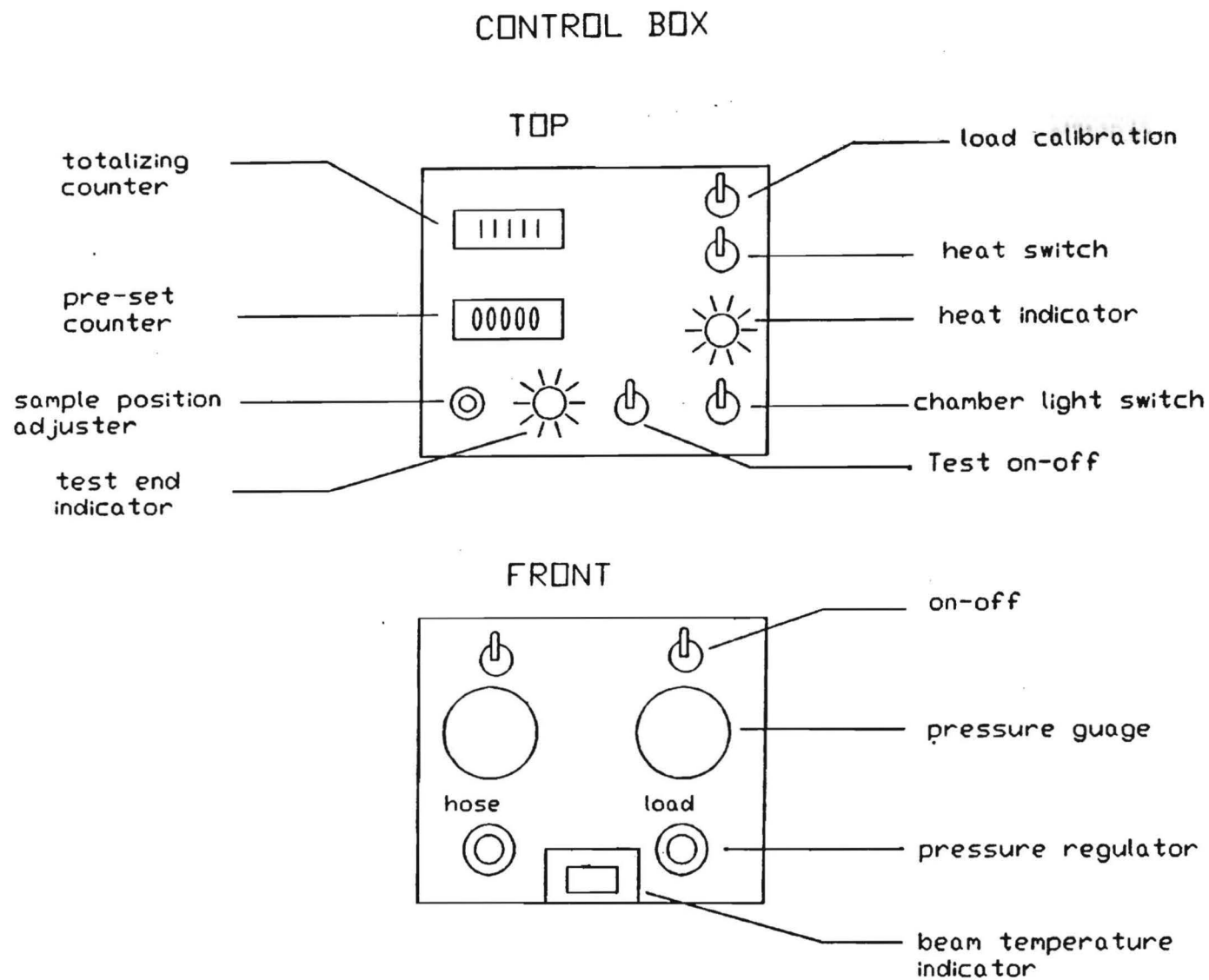


FIGURE 13 OPERATION CONTROL PANELS

CHAPTER 3 DEVELOPMENT OF ROLLING COMPACTION MACHINE

Presently the beam samples are prepared by the a static compaction process using a compression machine. One of the reasons of using a static compression machine to fabricate the asphalt beam samples is that the machine is usually available in a testing laboratory. The static compaction procedure that has been used so far for preparing the beam samples is in general producing satisfactory density requirements, although the procedure is viewed to be too cumbersome. Furthermore, there is a concern that the static compaction procedure in fabricating the asphalt beam samples may not be able to produce asphalt samples with the properties similar to that produced in the field by compaction rollers. In the course of this research project a different asphalt beam sample preparation process using a rolling compaction was developed. This compact and self contained beam sample compaction machine should improve the deficiencies of the static compaction process mentioned above.

Figure 14 shows the rolling compactor. The compactor consists of four basic components, the sliding motion assembly, the rolling wheel compactor, the operation control system and the beam sample mold. The main features of each of the components are presented in the following.

Sliding Motion Assembly

This assembly, see Fig. 15 and 16, composed of a 15 in. wide by 24 in. long by 1 in thick steel plate attached with 4 heavy duty roller bearing at the bottom, The beam sample mold and the restraints are attached on the top of the plate. The sliding plate is attached to a double action hydraulic cylinder aligned horizontally at the bottom. When

the horizontal hydraulic cylinder rod is extended and retracted at a constant rate, it will cause the sliding plate and the beam samples secured on top of it to move back and forth in reciprocating motions.

Roller Compactor

The compaction roller is to apply a vertical compaction load on the beam sample. The system, see Fig. 17, consists of a load frame made of 4 threaded posts attached to a top and a bottom plate, a double action hydraulic cylinder attached to the top plate, and a roller attached to the cylinder rod. This compacting roller is capable of applying up to 12000 lb of compaction load on the beam sample. Two horizontal restraining bars, see Fig. 14, are installed between the roller clevis to restraint the horizontal movement of the roller due to the shear forces induced between the beam sample and the roller during the rolling compaction. This is needed to prevent excessive wear of the cylinder bearing. During the beam sample compaction, the roller exerts a vertical force on the rubber pad (or a teflon pad) and the thin steel plate which distribute this vertical force to the asphalt mix. The combination of the horizontal reciprocating motion of the beam mold and the vertical force from the roller creates the rolling compaction effect on the asphalt mix confined in the beam mold similar to an asphalt mix being compacted in the field by a roller.

Beam Sample Mold

Figure 18 shows schematically the beam sample mold assembly. It consists of a split beam sample mold made of 0.25 in. thick steel plates, a loosely fitted bottom plate and the constraints made of heavy steel angles. The constraints are bolted down on the sliding plate to confine the thin steel beam mold during the beam sample compaction, see Fig. 19. In the normal sample compaction operation, only one constraint needed to be

removed to free the beam mold while the other constraint can be permanently attached to the sliding plate. This can simplify the beam sample compaction operation somewhat.

Hydraulic System and Operation Control

Figure 20 shows schematically the hydraulic system for controlling the horizontal sliding motion and the vertical loading. The horizontal reciprocating motion is controlled by a horizontal actuator with the speed adjustable by a flow control valve. When this actuator is activated from an "ON-OFF" toggle switch, see Fig 21, the solenoid causes the actuator to move horizontally in one direction. This pushes the sliding plate and causes the plate to slide at a constant speed in one direction (with the roller bearings roll along the rails) until the plate contacts a limiting switch positioned at the extreme end of the horizontal movement, see Fig. 19. When the limiting switch is activated by the contact, it causes the solenoid to reverse the direction of motion of the actuator. This causes the sliding plate to move at the reverse direction until it contacts the other limiting switch positioned at the other extreme end of the traveling. Activation of this limiting switch again will cause the actuator to reverse the direction of the motion of the sliding plate. Thus, the sliding plate will automatically slide back and forth with the range of the horizontal movement set by the two limiting switches and with the speed of the motion set by the flow control valve. This reciprocating motion continues automatically while the ON-OFF switch remains at ON position while the cyclic switch on "CYCLE" position and will stop when it is switched to "OFF" position.

The vertical loading is controlled by "UP" and "DOWN" switches on the control panel. When the "DOWN" switch is activated, the solenoid causes the vertical actuator to extend and applied a vertical load on the beam sample via the compacting roller. The magnitude of the vertical load is manually controlled by a pressure regulator with the pressure shown on the pressure gage. During the sample compaction, the vertical compaction load should start at a low magnitude and gradually increase until the desirable beam density compaction requirements achieved.

An 1-1/2 in. thick stiff rubber pad (subsequently replaced with an 1-1/2 in. thick teflon pad) is placed on top of the loose asphalt mix, see Fig 18. In this arrangement, the vertical force from the roller is applied on top of the rubber pad, which distributing the force to the asphalt mix while the beam mold which confined the asphalt mix undergoes the sliding motion. This compaction action is very similar to the rolling action generated by a roller compaction of asphalt mixes in the field.

The machine is equipped with a vertical limiting switch which is to be used to control the maximum downward movement of the compacting roller. This limiting switch is properly positioned so that when the beam sample has been compacted to the approximate desirable depth, this limiting switch will be activated and cause the actuator to retract. This automatically stops the vertical actuator from overcompacting the beam sample. Additional compaction can be applied to the sample by manually depress and hold the "DOWN" button. The actuator will again extend and continue to exert load on the beam sample until this button is released. A horizontal line inscribed on the side of the teflon pad can be used as the reference for detecting any uneven depth of the beam sample which occasionally might occur in the course of the compaction. The possible causes and ways to

correct ~~them~~ are described in the Appendix B. The position of this reference line was carefully determined so that when this line is flushed with the top edge of the beam mold, the beam sample has been compacted to exactly 3 in. thick.

The loading of the vertical actuator can be activated only when the horizontal sliding action is already in motion. Anytime when the cyclic switch is turned to OFF and the sliding action is stopped, the vertical actuator will automatically retract. This will prevent the vertical load to press against the beam sample when the horizontal motion is accidentally stopped.

With the use of a split beam mold, the compacted beam sample can be removed readily from the beam mold. However, if a fixed beam mold is used instead this machine can also be used to extrude the beam sample from the mold. This can be done by placing the beam mold (with the sample in it) upside down, placing the wood block on top of the beam sample, and centering the beam mold under the compacting roller. When these are done, turn on the pump and the power, turn the extrusion switch to "EXTRUDE" position and hold down the "DOWN" button. This will cause the vertical cylinder to extend and apply load on the wood block to force the beam sample down from the mold.

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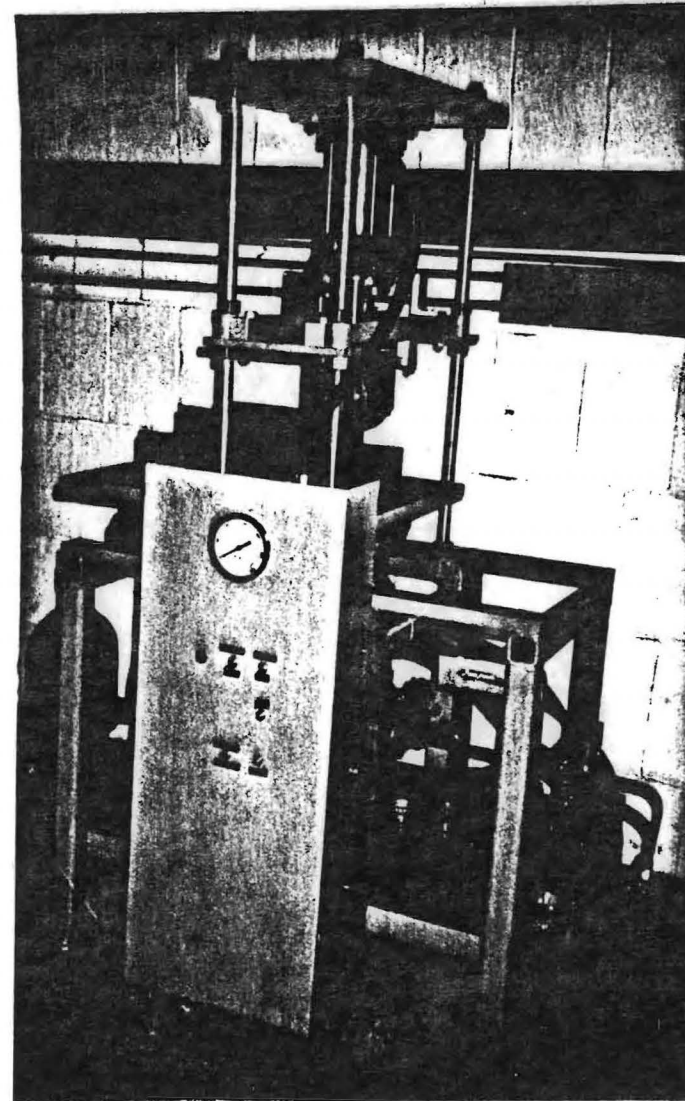
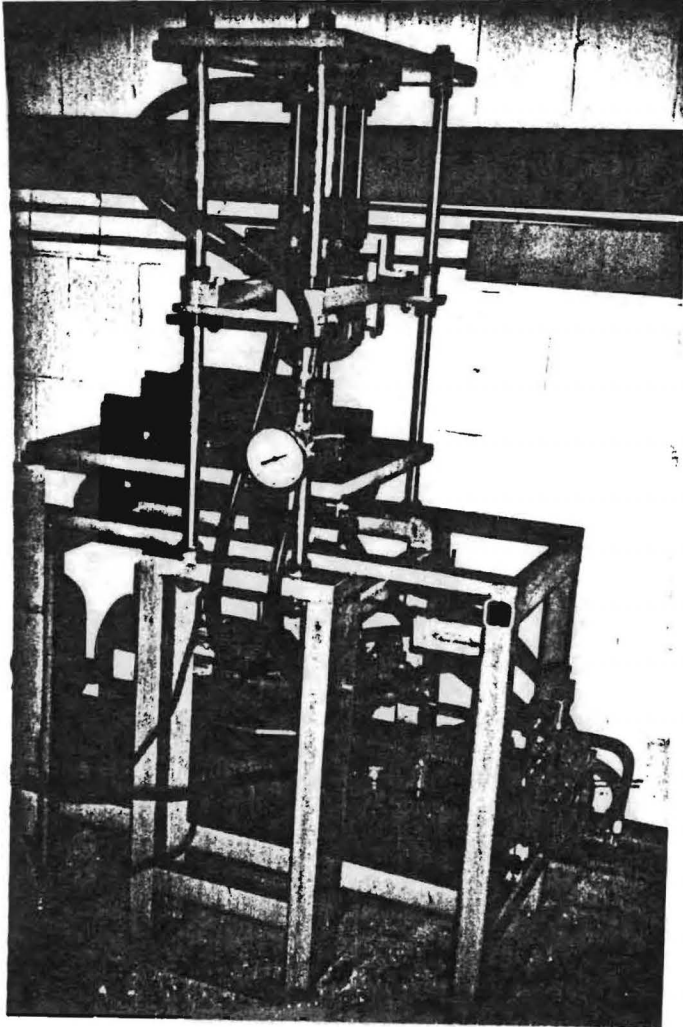


FIGURE 14 ROLLING COMPACTION MACHINE

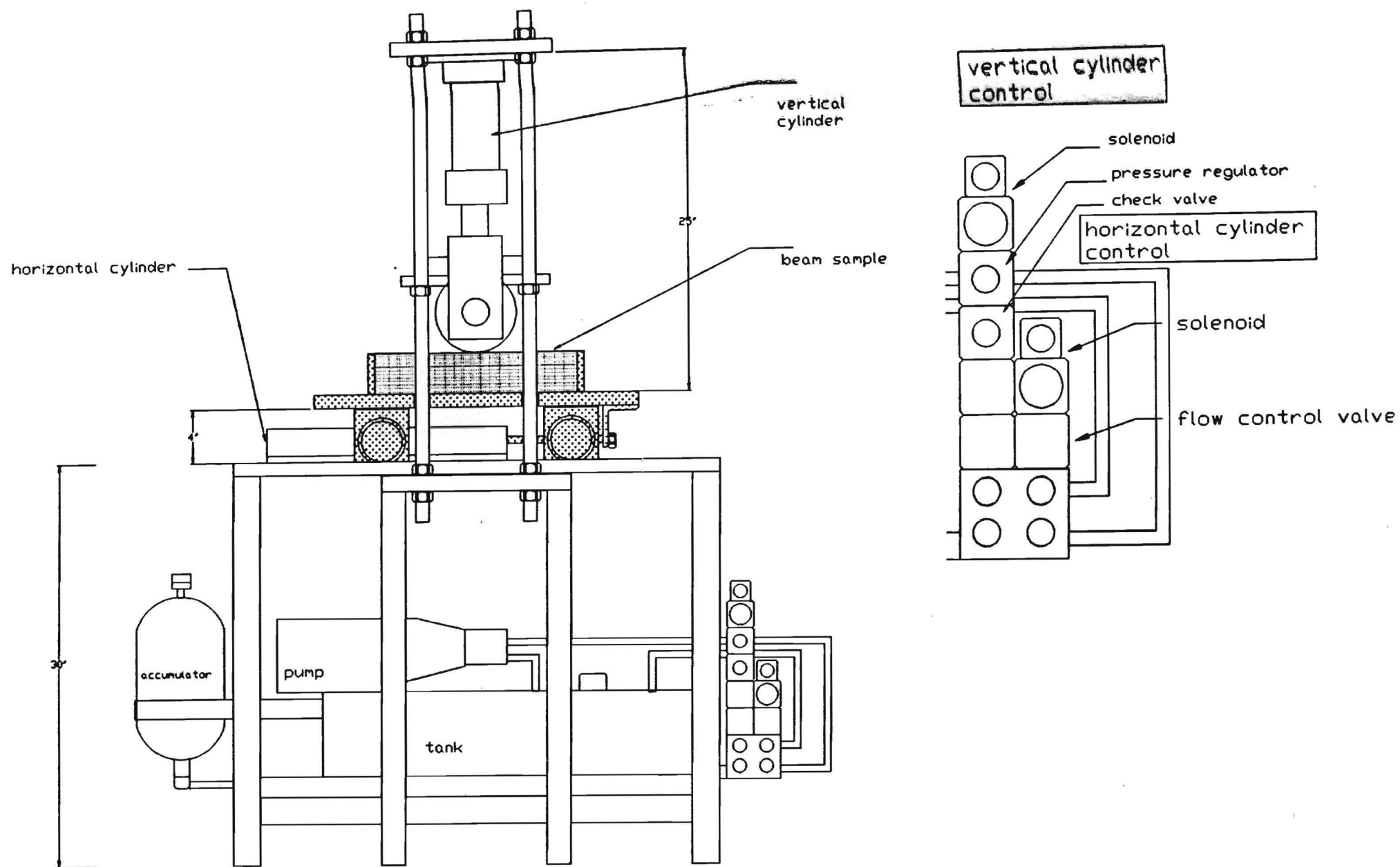


FIGURE 15 ROLLING COMPACTION MACHINE CYCLIC MOTION ASSEMBLY (FRONT)

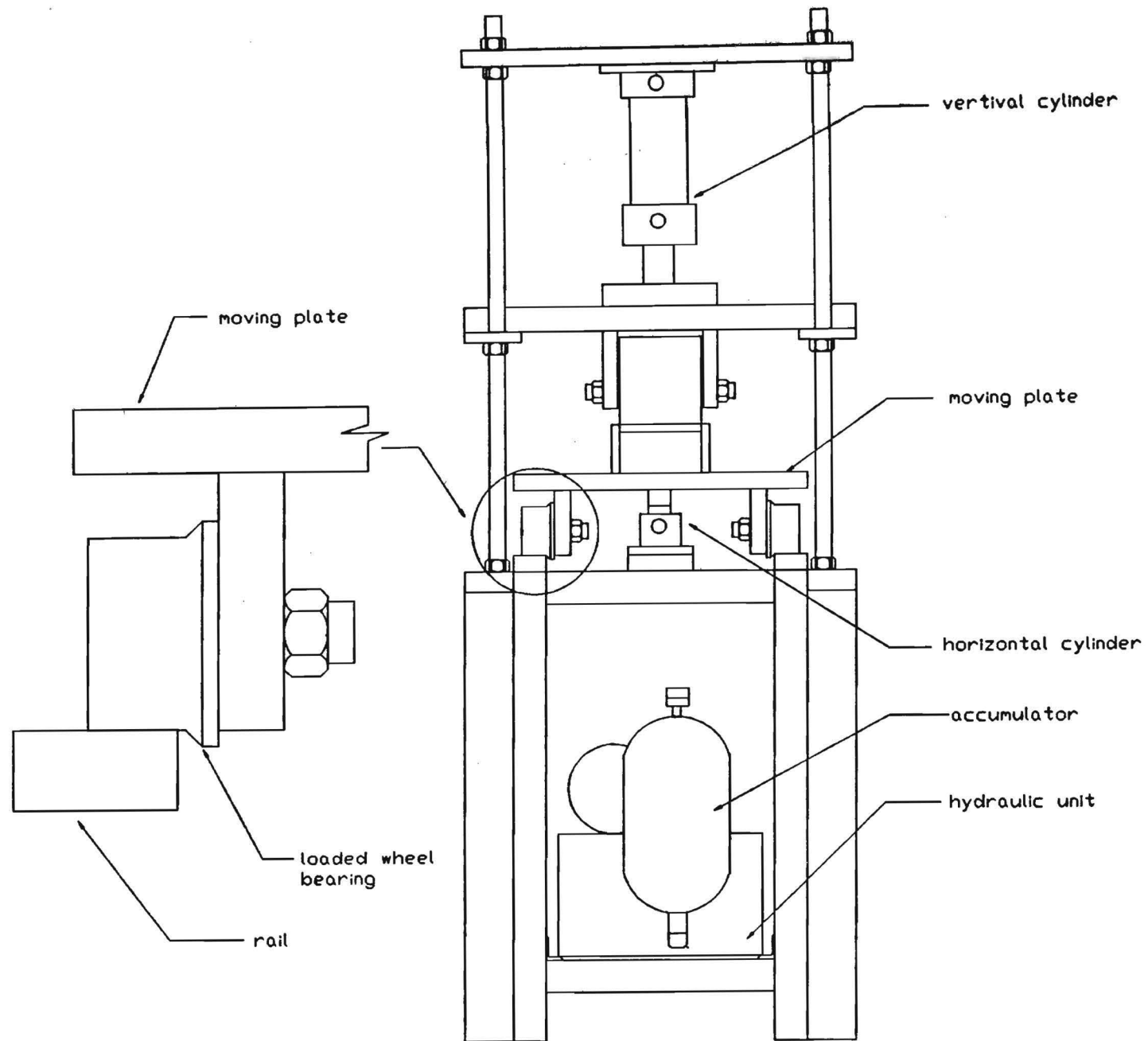


FIGURE 16 ROLLING COMPACTION MACHINE CYCLIC MOTION ASSEMBLY (SIDE)

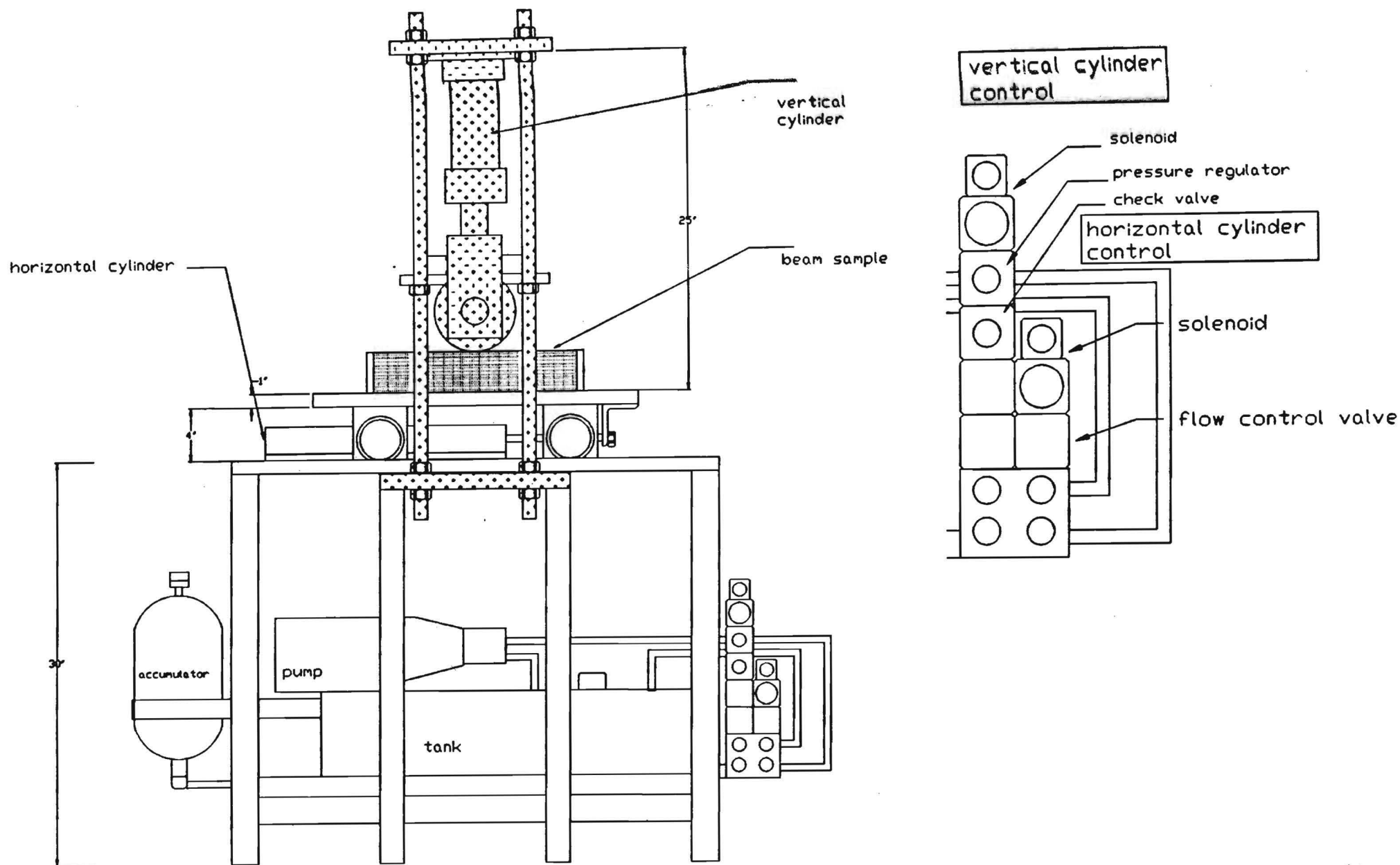


FIGURE 17 ROLLING COMPACTION MACHINE LIADING SYSTEM

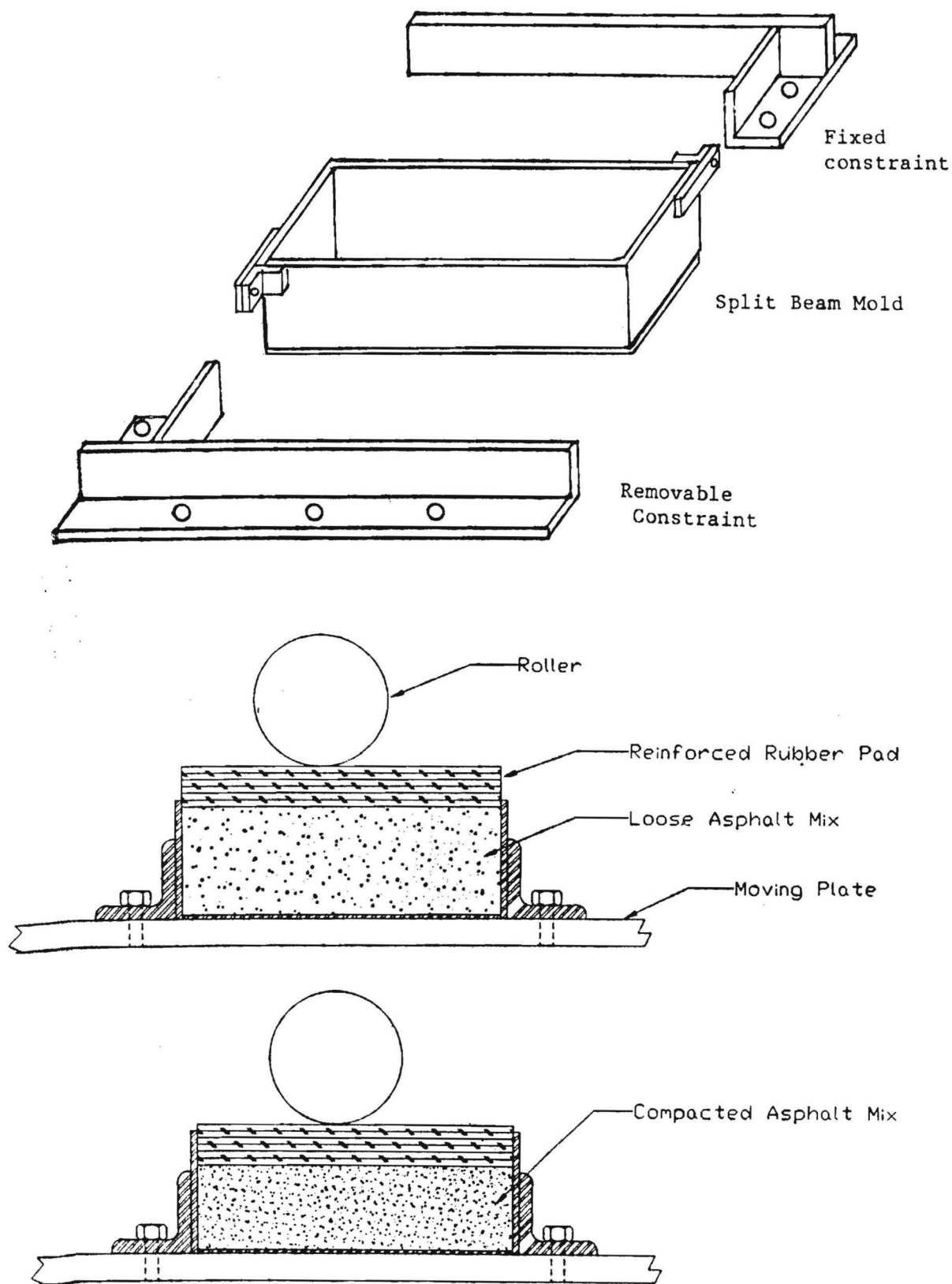


FIGURE 18 BEAM SAMPLE MOLD ASSEMBLY

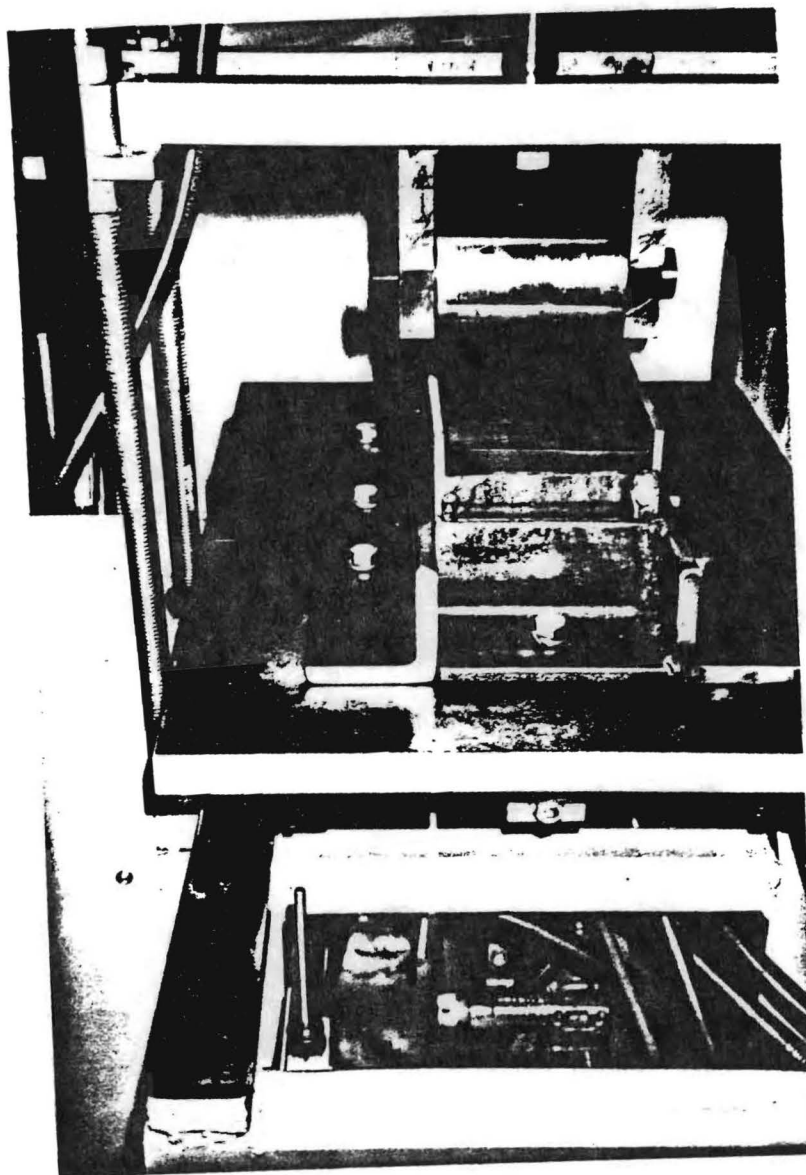


FIGURE 19 BEAM SAMPLE MOLD ASSEMBLY (PHOTO)

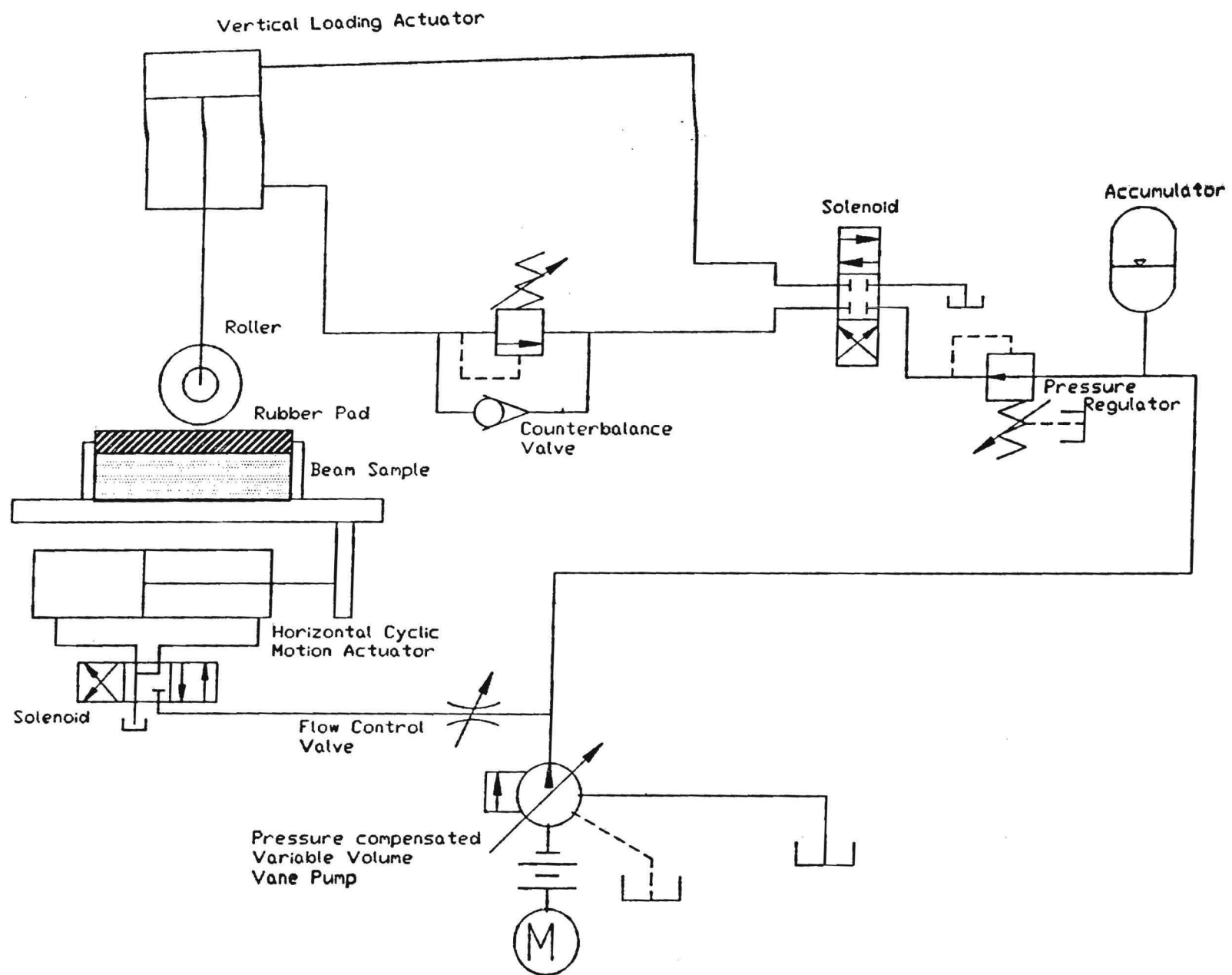


FIGURE 20 ROLLING COMPACTION HYDRAULIC SYSTEM CONTROL CIRCUIT

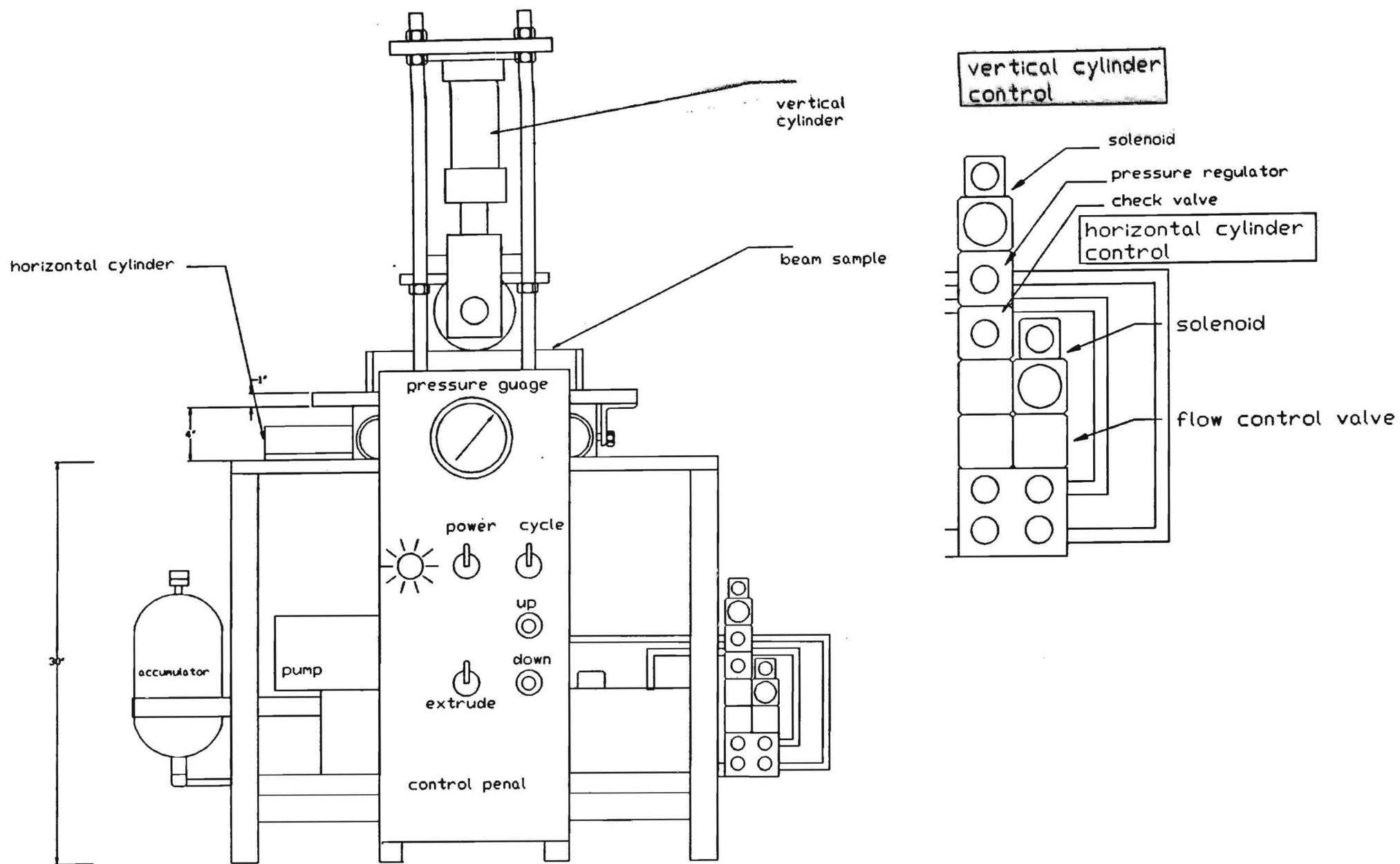


FIGURE 21 ROLLING COMPACTION MACHINE CONTROL PANEL

CHAPTER 4 SUGGESTIONS AND RECOMMENDATIONS

In the course of evaluating the performance of the new loaded wheel tester and the rolling compaction machine developed in this project, we have come up with a number of improvements for the machines. We believe that incorporating of these improvement ideas can further improve the performance of these machines. These improvement ideas are listed in the following.

4.1 Loaded Wheel Tester

1. Use of roller bearings and rails instead of the unistrut channel sections and bearings.
2. Use a larger control box and rearrange all control functions to be on the front panel.
3. Add retractable wheels on the bottom frame.
4. Add a stiff frame and a plate on the right side of the chamber, between the sliding plate and the bottom insulating penal or above the sliding plate for use to preconditioning the beam samples.

4.2 Rolling Compaction Machine

1. Increase the length of the threaded posts by 4 inches and increase stroke of the vertical cylinder to 6 inches.
2. The overall capacity of the hydraulic power system can be reduced. Use a single phase motor instead of the 3 phase motor. The accumulator can be eliminated from the system. Use an external pressure regulator to allow it to be attached on the control panel.

3. The length of tracks and stroke of longitudinal cylinder can be increased for compacting longer beam samples.
4. Use rigid steel piping instead of flexible piping for the hydraulic system.

APPENDIX

APPENDIX A

Operation Procedure for Loaded Wheel Testing

A. Place and Secure Beam Samples

1. Open the front door and pull the beam sample holding plate partially out. Be careful not to pull the plate too far out, the plate may tip. Use the sliding plate position adjusting button on the control panel to position the sample holding plate right at the front door.
2. Place the first beam sample on the beam sample holding plate against the back side restraining bracket and the left end restraining bracket, tighten the right end restraining angle bracket against the right end of the specimen. Note that the back side and the left end restraining brackets are normally bolted down on the beam sample holding plate and need not be loosen or removed when replacing the beam samples. Place the U-shaped side restraining bracket firmly against the front side of the first beam sample. This bracket does not need to be bolted down.
3. Place the second beam sample against the U-shaped bracket and the left end restraining bracket, and tighten the right end restraining angle bracket.
4. Repeat the same procedure for setting up the third beam sample. The front side of the third beam sample is confined by an angle bracket. This bracket should be bolted down on the beam sample holding plate.
5. With all three beam samples properly secured, measure the initial beam surface profile using the rut depth measurement stand and the electronic indicator. The procedure for making the measurement is described in C-2 in the following.
6. After that, push the beam sample holding plate back and secure it on the sliding plate and close the front door.

B. Start Loaded Wheel Testing

1. Set the "PREDETERMINING COUNTER" to the number of repetitions for the test to be run.
2. Reset the "TOTALIZING COUNTER" to zero, if needed.

3. Check the chamber temperature to ensure that temperature in the beam samples has been stabilized and at the testing temperature.
4. Check the pressure gage reading for the pressure in the hoses. Use the pressure regulator directly under the pressure gage to adjust the pressure, if needed.
5. Check the pressure gage reading for the pressure to be applied by the air cylinders. The calibration chart between the pressure reading and the load applied by the air cylinders is posted on the right side of the control box. Use the pressure regulator directly under the pressure gage to adjust the pressure, if needed. Check the ball valves directly above each cylinder which should be at the open position (pointing horizontally).
6. Switch the "LOAD" toggle switch to "ON" position. This will immediately cause the loading wheel to lower down and exert the preset load on the pressurized hose. After about 2 seconds delay, the reciprocating motion will start.
7. The test will continue until the preset number of repetitions has been completed and the "PREDETERMINING COUNTER" has counted down to zero. At this point, the test will be automatically terminated. The loaded wheel will retract; the reciprocating motion will stop and a red indicating light will be on. The number of repetitions during this test period should be indicated on the "TOTALIZING COUNTER".

C. Rut Depth Measurement

1. Open the front door to expose the beam samples. Use the sliding plate position adjusting button on the control panel to adjust the sliding plate position so that the beam sample holding plate can be pulled out from the front door. Loosen the latch and partially pull out the sample holding plate to expose the beam samples between the rubber hoses.
2. Place the rut depth measurement stand over the beam sample, and set the stand on the sample side constraints with the protruded section of the stand fit into the notch on the side constraint. Place the electronic indicator into the slots with its base rest firmly on the groove over the slot and slide the indicator along the groove to detect the maximum rut reading on the indicator. This maximum rut reading represent the deepest depression of the beam sample at this particular position. Record the reading. Proceed to the next slot and use the same process to obtain the max. rut reading at this slot position. After five rut readings have been taken from one beam sample, proceed to the next beam sample and do the same.

APPENDIX B

Beam Sample Compaction Procedure

A. Mix Design

Weight of aggregates, asphalt cement and admixture needed to fabricate the 3"x5"x12" asphalt beam sample should be determined to meet the actual laboratory density requirement at optimum asphalt cement content. Make two batches of aggregate samples with the weight of each batch equals 1/2 of the total weight of aggregate needed to fabricate the beam sample and the gradation meets the specified gradation requirements.

B. Mixing

Heat aggregate, asphalt cement, and utensils to the specified temperatures normally used in preparing asphalt mixes for the Marshall samples. The procedure for mixing the asphalt mixes is similar to that for preparing the Marshall samples. After mixing, place the entire batch of the mixture in an one gallon can, close lid and place in an oven set at an approximately 350 °F. Heat until mixture temperature is 10 °F above the normal compaction temperature for Marshall samples for the grade of asphalt cement being used.

C. Rolling Compaction

1. Remove the heated beam mold (including the side mold and the bottom plate) from oven, place on top of the moving plate. Secure the beam mold on the moving plate, and tighten bolts of the constrain bracket. Apply a light coat of oil on the inside surfaces of the mold.
2. Remove the can containing the mixture from oven, shake the can, remove lid, and pour entire batch of mixture in the mold. Spade the loose mixture in the mold thoroughly with bullet nose rod, level the mixture. Empty the second batch of the asphalt mixture into the beam mold, spade the loose mixture, after level the mixture, scrape some mix from the edges toward the middle to form a doom shape. Place the thin steel plate and the teflon pad on top of the asphalt mix. Tap the teflon pad with a mallet.
3. Turn on the pump and the power switches, and turn on the "CYCLE" switch. The sliding plate will start the horizontal cyclic motion. Before applying the vertical load, make sure that the pressure regulator has turned down (counterclockwise). Press the "DOWN" button to start the initial compaction loading. Turn the pressure regulator clockwise slowly to gradually increase the pressure to 200 pas. The roller should start to extend downward at about 150 psi. Allow the beam to be compacted under at 200 psi pressure for three full cycles. After that, increase the pressure by 50 psi each time

and allow 3 full cycles of compaction under each pressure reading until the beam sample is compacted to the required density. For E-mix, B-mix and SMA-mix the max compaction pressures required are approximately at 650 psi, 750 psi and 800 psi respectively. At this point, the horizontal reference line inscribed on the side of the teflon pad should be flushed with the top edge of the beam mold. The vertical limiting switch should be activated at this position to cause the roller to retract, if this switch has been properly positioned.

4. During the compaction, closely observe the evenness of the beam sample under compaction. This can be done by observing the distance between the reference line inscribed on the teflon pad directly under the roller and the top edge of the beam mold. If the initial pressure was too high relative to the internal shear resistance of the mix or the loose asphalt mix was not evenly placed in the mold, this may cause uneven compaction. This unevenness can be correct by applying intermittent loadings at the positions where the beam sample are relatively high. The intermittent rolling can be controlled by using the "DOWN" and "UP" buttons to manipulate the down and up movements of the roller.

5. When the required compaction has been achieved, turn off the "CYCLE" switch and the sliding plate will park at the far right and the roller will retract. Remove the teflon pad and the thin steel plate on top of the beam sample and remove the side constraint. Place the beam mold with the beam sample in it on a firm counter top.

6. Beam sample can be removed immediately from the beam mold by remove the two bolts which hold the split mold together, gently tap the beam mold to separate the split beam mold from the beam sample. To avoid disturbing the beam sample, it is suggested that the beam sample should be left on top of the bottom plate until the beam sample has been sufficiently cool down..

Appendix C

List of major parts

<u>Item</u>	<u>Manufacturer</u>	<u>Model No.</u>
<u>Loaded Wheel Tester</u>		
1. air cylinder (3)	Parker/Hannifin	L073801200
2. solenoid	Parker/Hannifin	52401-1115
3. limiting switch	Grainger	3A096
4. motor	Grainger	
5. gear reducing box	Grainger	
6. digital indicator	McMaster-Carr Mitutoyo Electronic	20875A67
<u>Rolling Compactor</u>		
1. hydraulic System:	Vicker	
2. hydraulic cylinder Rexroth 3 1/4" bore x 4" stroke		MF6HH
3. hydraulic cylinder Rexroth 1 1/2" bore x 12" stroke		MS2HH
4. roller bearing (4) McGill		FCF-3
5. limiting switch (3) Grainger		3A096