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16. Abstract

This study is a feasibility study of applying robotics technology to the process of making cement cube specimen in preparation for stress testing and measurement. This study includes the planning and design of a robotic workcell system and the technological and economical advantages of an automated process over the manual process in material testing and measurement. This study depicts the criteria for building a cost-effective automation system and the design considerations taken to achieve it. This study also raises the issue of the necessity of a revision of the ASTM standards to facilitate the future application of state-of-the-art technology to the material testing and measurement process.

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PROJECT NUMBER: 7-2928

THE USE OF ROBOTICS IN THE HYDRAULIC CEMENT MORTARS TESTING PROCESS

FOR

THE TEXAS DEPARTMENT OF TRANSPORTATION

PREPARED BY

TEXAS STATE TECHNICAL COLLEGE - SWEETWATER

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RONNIE L. MACDONALD
JOANNA M. KING

IMPLEMENTATION STATEMENT

As a conclusion of this study, the research team in Texas State Technical College should specifically consider the following for implementation in the design and construction of a robotic workcell:

1. The team should recognize that, although this report shows a preliminary design and represents a master blue print for the final product, the design will be continuously improved during the construction of the workcell.

2. The detail design of every component in the robotic workcell will be refined, based on the guidelines of this report, to perfect the process.

Prepared in cooperation with the Texas Department of Transportation

DISCLAIMERS

Sang-Shiun Chan
Research Supervisor
Texas State Technical College-Sweetwater

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. ABSTRACT

This study is a feasibility study of applying robotics technology to the process of making cement cube specimen in preparation for stress testing and measurement. This study includes the planning and design of a robotic workcell system and the technological and economical advantages of an automated process over the manual process in material testing and measurement. This study depicts the criteria for building a cost-effective automation system and the design considerations taken to achieve it. This study also raises the issue of the necessity of a revision of the ASTM standards to facilitate the future application of state-of-the-art technology to the material testing and measurement process.

II. INTRODUCTION

The Texas Department of Transportation (TxDOT) is funding the Automation/Robotics Department, Texas State Technical College-Sweetwater (TSTC), to study automating some of the tests that the TxDOT performs on construction materials while conforming to ASTM standards. About 3000 Portland cement samples per year are tested for compressive strength in the laboratory of the Materials and Tests Division of the TxDOT. These samples are mixed with standard-grade sand and water to form mortar cube specimens; and since the manual process of making these cube specimens consists of many repetitive actions, it makes good sense to apply robotics to the operator's repetitive tasks.

In the mortar making process, the operator weighs the materials needed, fills the molds with cement mortar and finally cleans the apparatus. These three tasks are constantly repeated. There are few variables in each task. One variable is the cement sample in every process cycle. The operator is the other variable crucial to the quality and consistency of specimens coming out of the process. In this process, the operator follows procedures set by the American Society for Testing and Materials (ASTM) to fill the molds with cement mortar and then tamps it to ensure that the mortar completely fills the mold. The tamping force varies from operator to operator. According to the field supervisor, the most important operator training is to ensure that the operator applies consistent tamping force. This consistency can be easily ensured by applying robotic tools, since a robot has no physical or emotional discrepancy with time and the surrounding. The tamping force is consistent since it is from the same robot and its attached tooling. Also, a robotic system can be reprogrammed within several minutes while a human operator requires several days to be retrained. Consistency and time saving easily justify the initial setup and daily operational costs of the robotic system.

The computer of the robotic workcell will store and print information regarding each cement sample. The operator will load the cement into the mixing bowl, then input information into the computer. The computer will store this information on a magnetic disk for future reference, then print out a report with each set of finished specimen. This function will save the operator time and energy from having to manually file related documents with each mortar sample. This setup automates the paperwork relating to the process.

III. RESEARCH STUDY

In the designing of this workcell, there are infinite ways to accomplish each task, but the most feasible and cost-effective design will be used. The goals of designing this automated robotic system need to meet the following criteria:

a) Comply with ASTM procedural requirements.
b) Pass the Cement and Concrete Reference Laboratory (CCRL) inspection checklist.
c) Be a fully-automated turnkey system.
d) Make use of off-the-shelf parts.
e) Be cost effective.

In observing the manual demonstrations of the tests done at the DOT laboratory, we noted that the ASTM has very strict rules and guidelines for the making of concrete samples. The ASTM standards do not leave much room for the use of automated equipment since this process has never been automated before. In the building of this workcell, we will make our best effort to conform to the ASTM standards. However, if we run into insurmountable problems, we will have to petition for a change of or a compromise with the rules. We need further discussion about making some modifications to the design to decide whether this robotic workcell could completely meet the national standard.

This robotic workcell will automatically do the following tasks: metering and pouring water, pouring sand, mixing the contents, pouring the mortar into the mold, tamping the mortar in the mold to ensure uniform filling, cleaning and drying everything exposed to the mortar and ingredients, acquiring data and processing documents.

The first thing we need to do is to see if we can buy off-the-shelf equipment that can be used in this workcell. The equipment should meet ASTM standards or be modifiable to be able meet these standards. The reason for using off-the-shelf parts as much as possible is for two purposes: First, is to keep the cost of building the system down, since the parts are not specially designed and made. Second, is to facilitate the ease of system maintenance, since there is no need to search for special parts. For example, the mixer and bowl, which are Hobart industrial-grade equipment, meet these requirements.

The decision of choosing an industrial robotic arm over a non-robotic mechanism is also based on the off-the-shelf objective. The one-time building cost of an industrial robotic arm seems higher, but the long-term overall cost for the system could easily be justified.

A non-robotic mechanism needs to be completely designed in-house, manufactured in the TSTC facility. It is difficult to estimate the total cost of the whole unit until it is completely built. Because it will be of a unique design, there will be little flexibility for modifications to the design after the workcell system has been built,. Modifications will entail a great deal of redesign and retooling. It is also difficult to get companies to commit to the long-term maintenance plan for this workcell because of its unique design. Therefore, the future operational and maintenance costs will be unpredictable.

As a result of the above factors, the TSTC team has determined to use the AdeptOne industrial robotic arm as the main operational mechanism. There are several merits with this decision: First, the AdeptOne industrial robotic arm is made by Adept Technology, one of the largest American industrial robot manufacturers with a significant market share. It assures quality design and long-term availability of service. Second, the robotic arm is a Selective Compliance Assembly Robot Arm (SCARA), which is the most popular robot design. This robot can be easily replaced by a robot from other manufacturers. Its compatibility makes acquisition and service costs very reasonable and predictable. Third, the robot will be completely software driven, meaning that changes in the process only necessitates reprogramming of the robot controller without involving drastic overhauling of the workcell system. The reprogramming work can be performed by a trained operator instead of an outside contracting company. There will be a big cost savings.

However, some components are not likely to be found in industry: For example, a device which unloads the contents of the bowl once the contents have been mixed; or a device that tamps the mortar inside the mold. In these cases, we have to resort to designing a new piece of equipment.

One of our main objectives is to build the workcell a turnkey system. An operator with minimal training and experience is able to run the machine with ease. Each piece of equipment that we build should be modular in design and easily repairable and adjustable. All equipment should be self-cleaning and self-monitoring to ensure proper working order and consistency. If a device in the workcell should malfunction, the operator's control panel should report the problem and give a probable course of action to solve the problem. It needs only one operator. The tasks of this operator include:

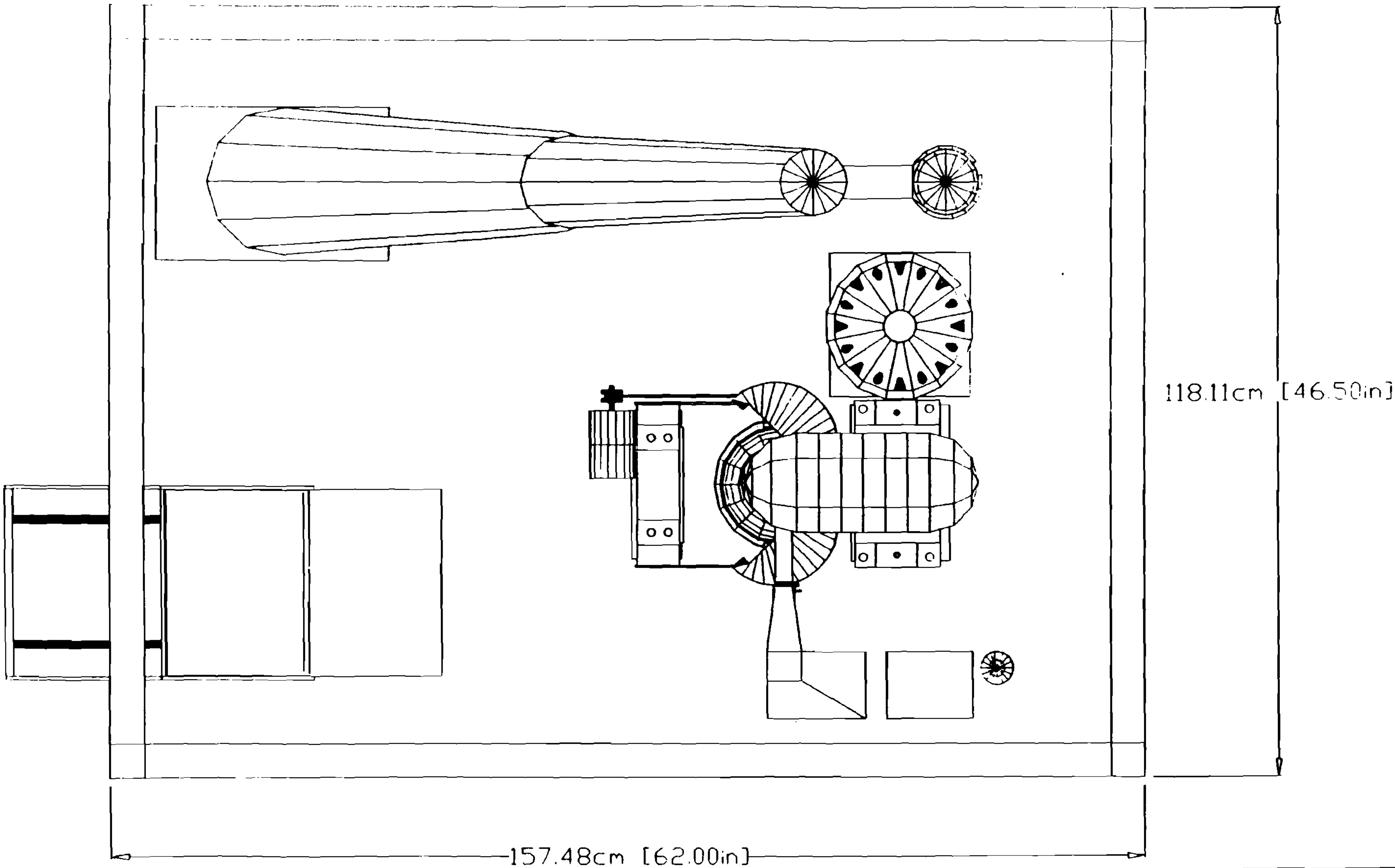
a) Weighing the sand and pouring it into the sand dispenser;
b) Weighing the cement sample and pouring it into the mixing bowl;
c) Keying information into the computer;
d) Trowelling the molds and cleaning their surfaces before placing them in the oven;
e) Cleaning the septic container at the end of each day.

As with all equipment, there will be a need for proper maintenance and calibration each month. This is to safeguard against any malfunction that may not be apparent. The unit will require a thorough visual inspection and cleaning, if required, once a day to prevent cement buildup on vital parts.

IV. DESCRIPTION OF THE SYSTEM

A) Complete System Layout (Refer to Figures 4.1, 4.2 and 4.3)

There are three figures to show the layout of this system. Figure 4.1 is the top view of this workcell. Figure 4.2 is the isometric view of the workcell without showing the sand and water dispensers. Figure 4.3 is another isometric view of the workcell without showing the sand and water dispensers.

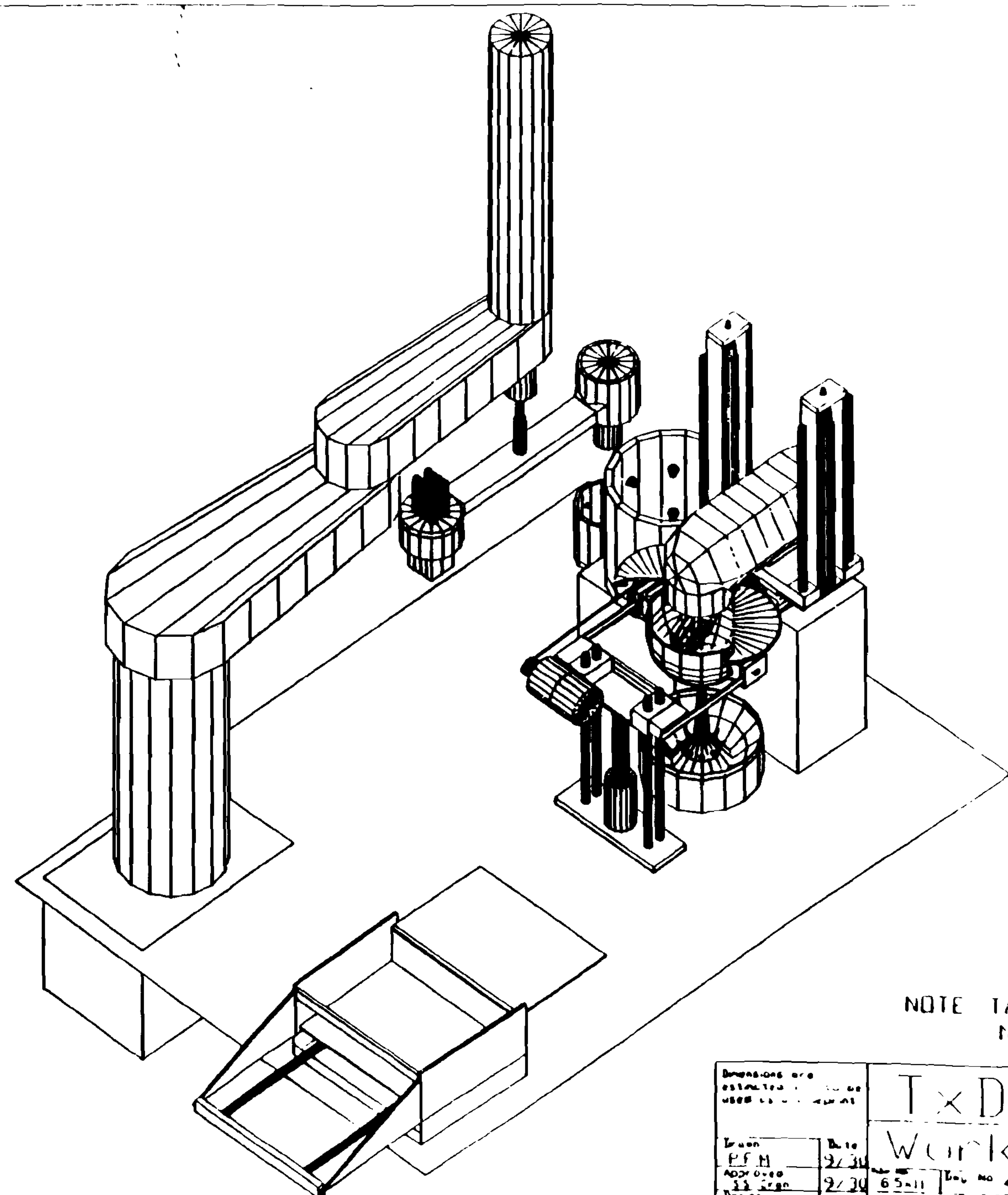


Dimensions are estimated, not to be used as a blueprint

TxDOT/TSTC

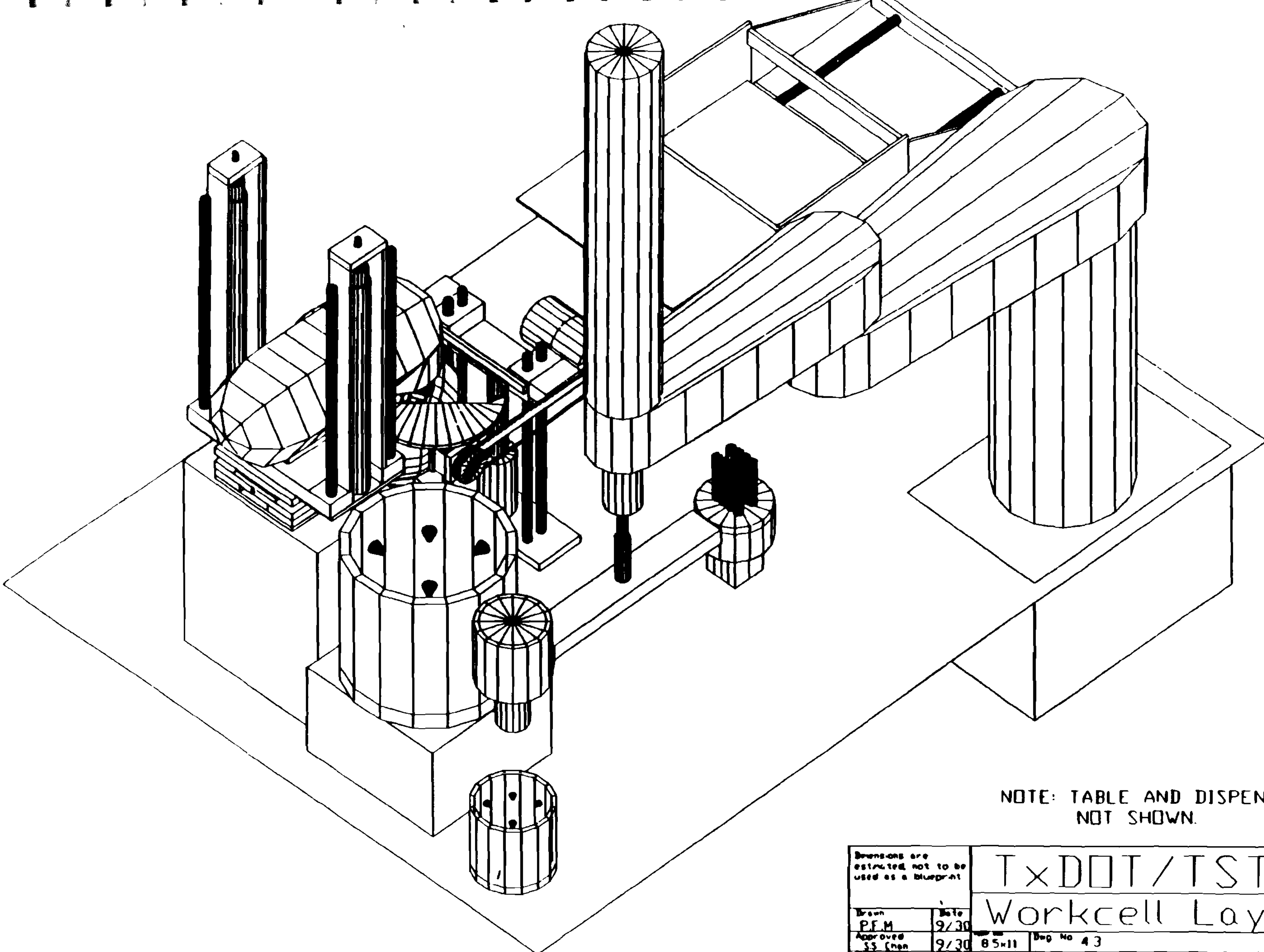
Workcell Layout

Drawn	Date	Size	Dwg No	REV
P.F.M.	9/30			
Approved S.S. Chan	9/30	8.5x11	4.1	A
Design S.S. Chan	9/30	Scale NTS		Figure 4.1



NOTE TABLE AND DISPENSERS NOT SHOWN

Dimensions are estimated ... used ...		TxDOT/TSTC
Drawn PFM	Date 9/30	Workcell Layout
Approved SS Cron	9/30	6 Sm.. Dwg No 4 2 Rev A
Design SS Cron	9/30	Scale NTS Figure 4 2



NOTE: TABLE AND DISPENSERS NOT SHOWN.

Dimensions are estimated not to be used as a blueprint		TxDOT/TSTC		
Drawn P.F.M	Date 9/30	Workcell Layout		
Approved S.S. Chen	9/30	8.5x11	Dwg No 43	REV A
Design S.S. Chen	9/30	Scale NTS		Figure 43

B) Equipment

The following is a listing of the equipment to be used in the automation.

1. Enclosure of the workcell

   The workcell is a completely enclosed booth so that the temperature and humidity inside can be controlled. The enclosure will be of 0.635 cm (1/4 in)-thick plexiglass walls.

2. Structure of the enclosure

   The frame will be constructed of 9 cm (3.54 in)-by-9 cm (3.54in) structural beams from Bosch. This sturdy frame is made of specially constructed anodized, extruded aluminum.

3. Table

   The table will be wood and measure 182.88 cm (6 ft) by 243.84 cm (8 ft) and 5.08 cm (2 in) thick. The top of the table will be covered with a layer of stainless steel.

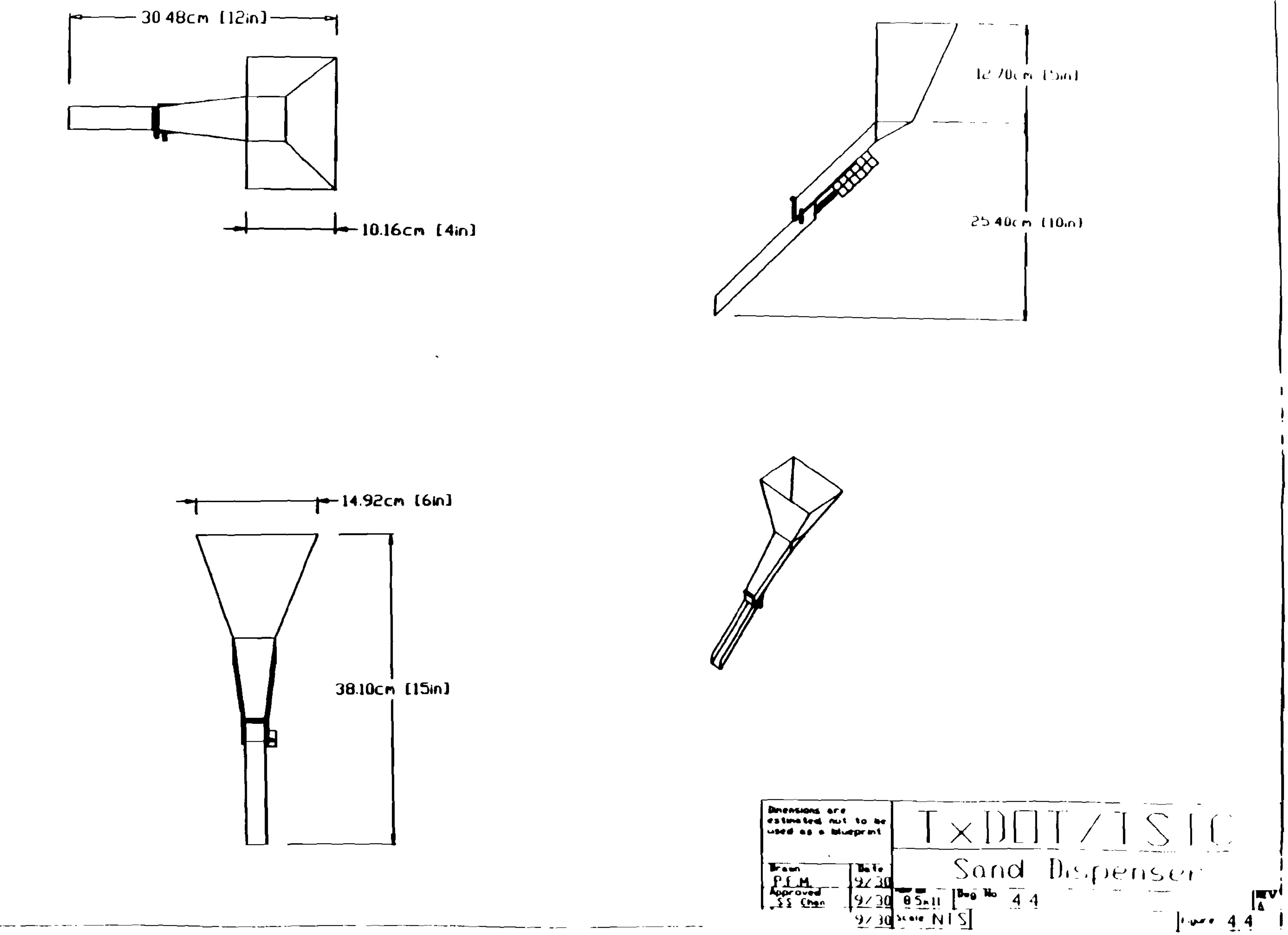
4. Sand and water dispensers (Refer to Figures 4.4 and 4.5)

   a) The pre-weighed sand will be poured in a sand dispenser. When it is time to pour, a section of metal channel extends out and a lever attached to the channel opens the door at the bottom of the dispenser to release the contents down the channel into the mixing bowl. The opening of the door could be adjusted so that the sand is poured over a period of exactly thirty seconds while the mixer is running.

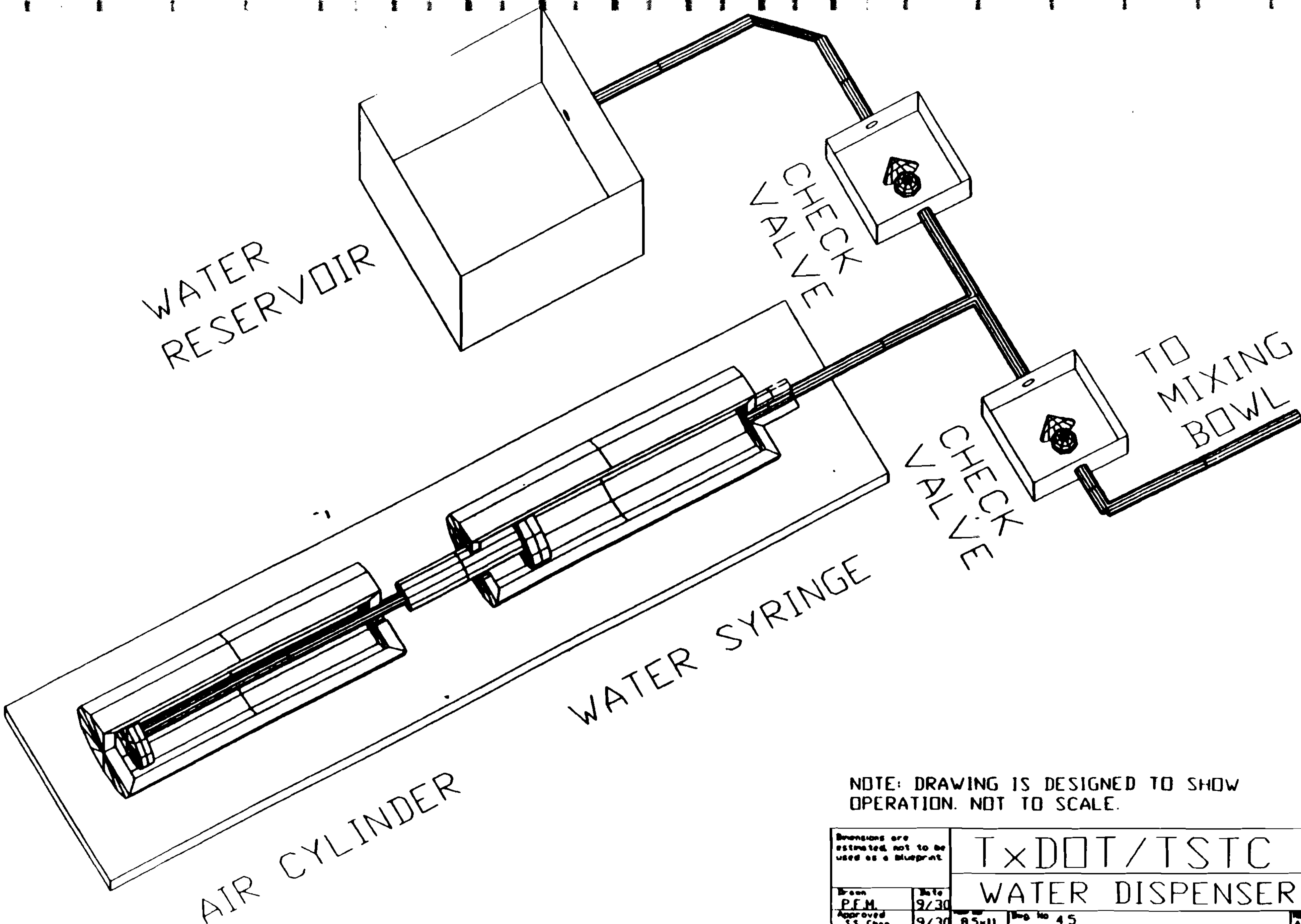
b) The design of the water dispenser incorporates a syringe, an intake port and an exhaust port. A main reservoir will contain all the water. The intake port will be connected to the main reservoir through a check valve. Likewise, the exhaust port will feed into the mixing bowl through a check valve.

When it is time to dispense water, the plunger in the syringe will pull back, while the check valve adjoining the reservoir will open, allowing water from the reservoir to flow into the syringe. At the same time, the check valve atop the mixing bowl will close, preventing air from entering the syringe. The plunger will pull back until the exact amount of water has entered it.

When the syringe is full, the plunger will start to push out, the check valve adjoining the reservoir will close, preventing refilling of the reservoir. Meanwhile, the check valve atop the mixing bowl will open so that the water can pour in. The plunger will be driven by a servo-controlled pneumatic cylinder. This pneumatic cylinder is controlled by the system controller. Through the computer, the operator will be able to make adjustments and calibrations as they are needed.



30.48cm [12in]
10.16cm [4in]
12.70cm [5in]
25.40cm [10in]
14.92cm [6in]
38.10cm [15in]
Dimensions are estimated not to be used as a blueprint
TxDOT/TSTC
Sand Dispenser
Drawn P.F.M.
Approved SS Chen
Date 9/30
9/30
9/30
Scale NTS
Dwg No 4.4
Figure 4.4

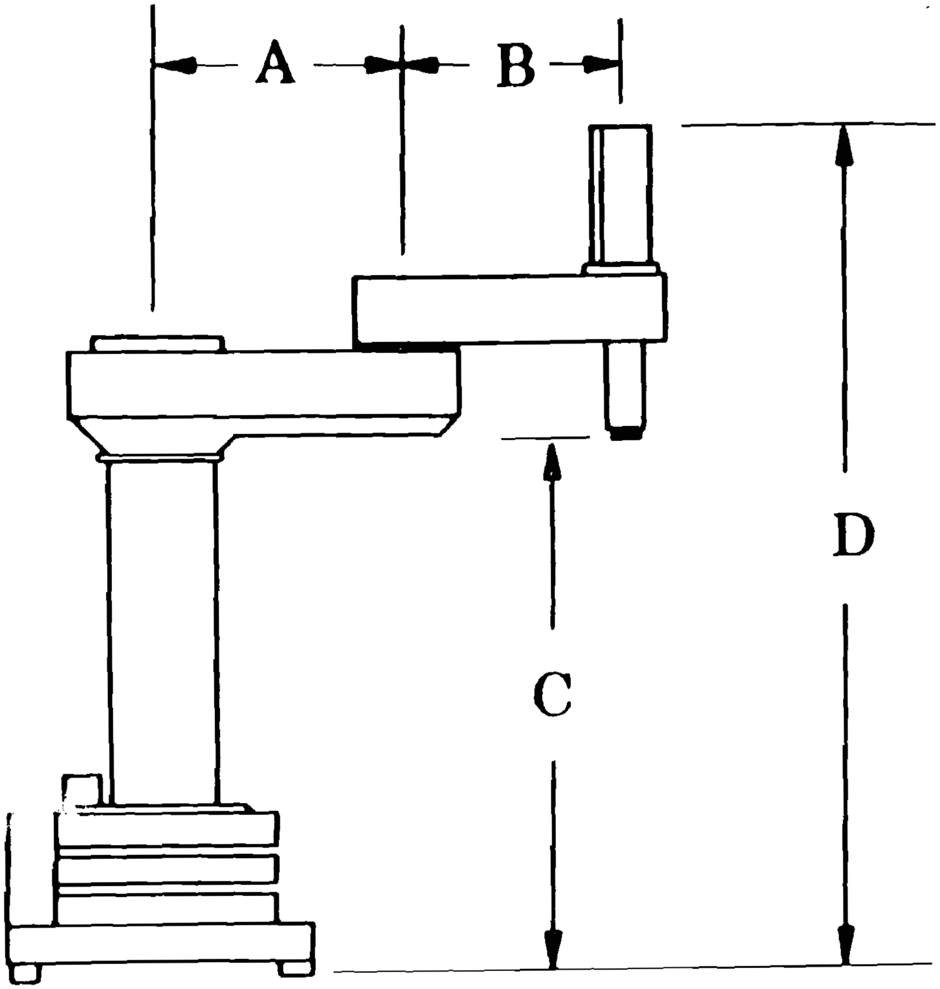


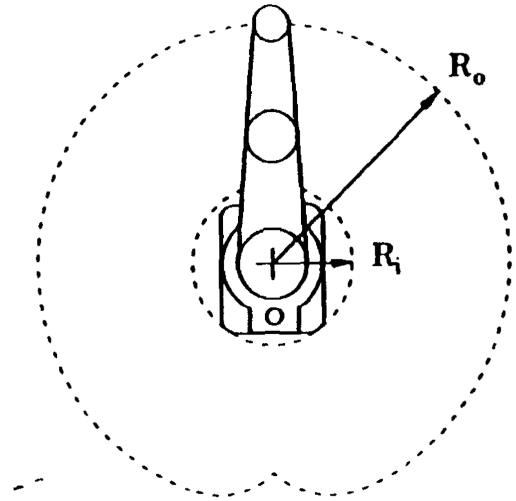
NOTE: DRAWING IS DESIGNED TO SHOW OPERATION. NOT TO SCALE.

Dimensions are estimated, not to be used as a blueprint.		TxDOT/TSTC
		WATER DISPENSER
Drawn P.F.M.	Date 9/30	
Approved S.S. Chen	9/30	Size 8.5x11 · Dwg No 4.5 · REV A
Design S.S. Chen	9/30	Scale NTS · Figure 4.5

5. Robotic arm (Refer to Figure 4.6)

An AdeptOne SCARA robot, manufactured by Adept Technology, will be used. The robot has a reach of 80.01 cm (31.5 in) with a vertical stroke of 29.46 cm (11.6 in) and a maximum load capacity of 9.072 kilogram (20 lb).





AdeptOne Dimensions

A –	Inner link:	16.73"
B –	Outer link:	14.76"
C –	Vertical clearance (base to retracted quill flange)	
	with 7.7" stroke:	34.5"
	with 11.6" stroke:	30.5"
D –	Manipulator height	
	with 7.7" stroke:	59.0"
	with 11.6" stroke:	63.0"
R_o –	Maximum reach:	31.5"
R_i –	Minimum reach:	9.0"

Dimensions are estimated, not to be used as a blueprint

TxDOT/TSTC

ROBOT ARM

Drawn P.F.M.	Date 9/30	8.5x11	Dwg No 4.6
Approved S.S. Chan	9/30	Scale NTS	Figure 4.6
Design			

6. Central control unit

This unit is the brain of the workcell. It contains all the electronic control circuits and computers. It controls the robot and the sequence of the operation of the workcell. Through the unit, the operator can program and monitor the operation of the workcell.

The central control unit contains an operator's control panel and a workcell control station.

a) The operator's control panel: This device is to show the operational status of the workcell. It is also the device through which the operator can operate the workcell. The panel of the control unit contains indicator lights such as a READY light, a RUN light, a STOP light, a MOLD READY light, ERROR lights, and push buttons such as a START button, a STOP button, a RESET button and a NEW MOLD button. There is also an E-STOP button on the panel.

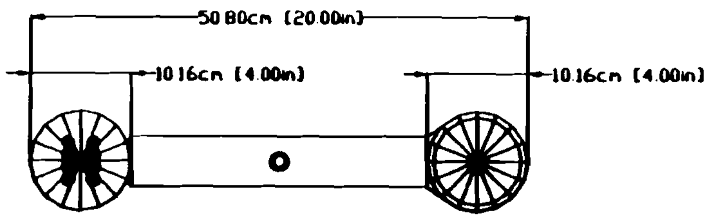
b) The workcell control station: This station includes a robot controller, a programmable controller, a monitor and a printer. The robot controller will be the Adept A-Series. There are 512 input/output ports and one color graphics workstation. Through the control station, a programmer can program and control the robot motion sequence and all the mechanisms used in the workcell. The information related to the cement sample is keyed into, stored in and printed out from this station.

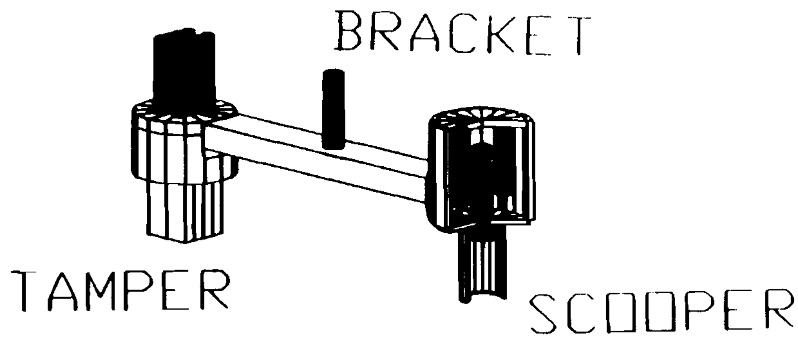
7. End-effector (Refer to Figure 4.7)

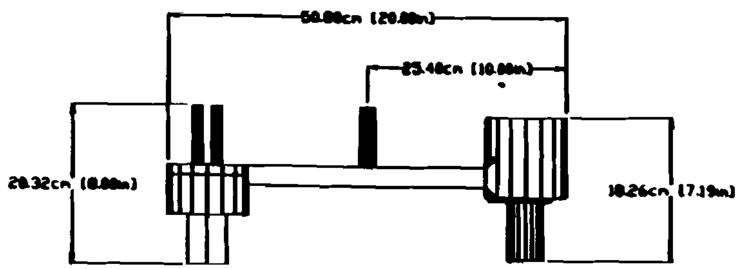
a) The end-effector bracket will be connected to the quill of the robot. This bracket will be used to connect the scooper and the tamper. All tubes and wiring will be run inside the bracket so that there will be no exposed items to entangle with nearby apparatus.

b) The bracket will be made of aluminum. This material is light and strong enough to hold the two end-effectors.

c) The end-effector will have two mechanisms attached to it. One is the scooper used to take the mortar out of the bowl and place it into a mold. The other is the tamper used to tamp the mortar in the molds evenly.







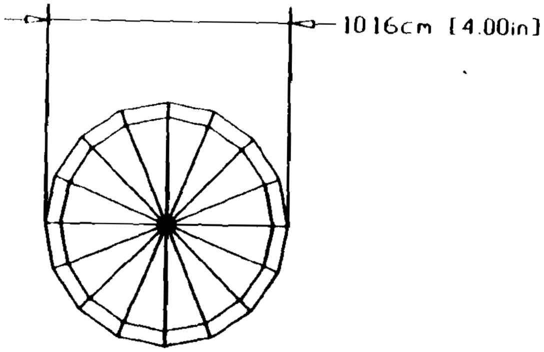
Dimensions are estimated not to be used as a blueprint	TxDOT/TSTC		
	End Effector		
Drawn P.F.M.	Date 9/30		
Approved S.S. Chan	9/30	8.5x11	Dwg No 47 — Rev A
Design S.S. Chan	9/30	Scale NTS	Figure 47

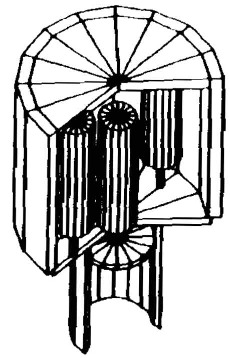
8. Scooper (end-effector) apparatus (Refer to Figure 4.8)

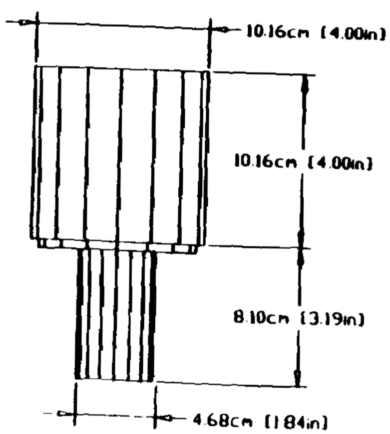
Extracting precise amounts of mortar from a bowl is a problem because the ASTM standards do not allow changes in the design of the bowl. Therefore, the only way to retrieve mortar is to extract it from above. In the experiments where a jaw-like scoop was used to extract the mortar, unpredictable amounts of mortar was extracted. The best way to remove mortar, we found, was to use a tube-like scooper.

The scooper is operated in similar fashion to the device that the geologist uses to take core samples from the top soil. It is a small tube that the robot inserts into the mortar mix. The mortar is forced into the tube by suction when a plunger inside the tube pulls back, providing a vacuum to ensure that the mortar stays inside the tube. Then, the robot end-effector will twist, breaking the mortar adhesion. The end-effector will then move over to the molds where the plunger will extend, pushing the mortar out and depositing it into the molds. After it has completed depositing the mortar into all the molds, the end-effector will move to the cleaner to be cleaned.

The robot will use an algorithm to move the scooper around the bowl to extract the mortar multiple times to ensure that the entire volume of the cylinder is filled. This is to ensure that an accurate amount of mortar is fetched out of the bowl.



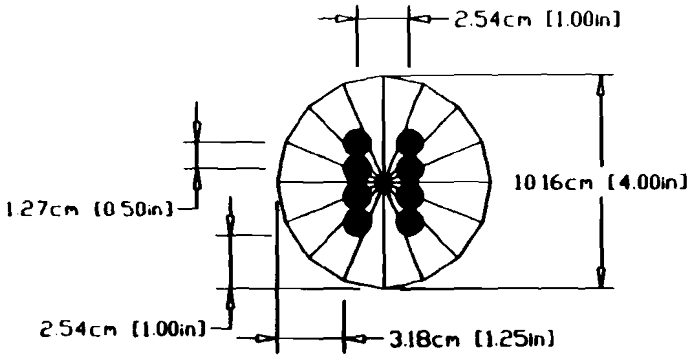


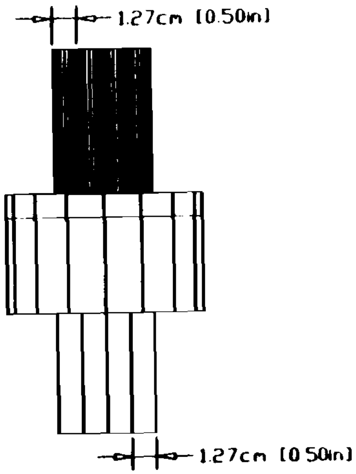


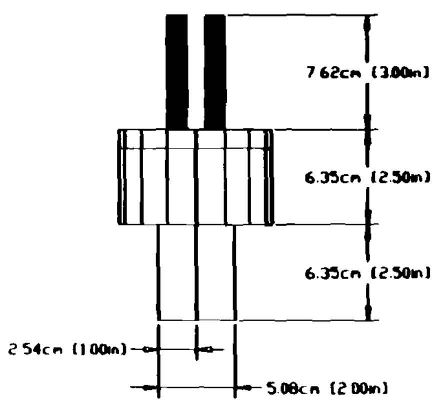
Dimensions are estimated not to be used as a blueprint		TxDOT/TSTC
Drawn P.F.M.	Date 9/30	Scooper Detail
Approved S.S. Chen	9/30	8.5x11 — Dwg No 48 — REV A
Design S.S. Chen	9/30	Scale NTS — Figure 48

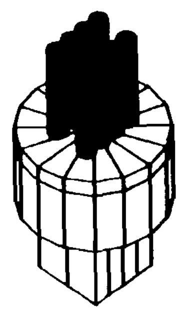
9. Tamper (end-effector) apparatus (Refer to Figure 4.9)

The tamper plays an important part in making an accurate test specimen. It is used to ensure that the mortar is evenly distributed throughout the mold. Automating this part of the process would guarantee uniform tamping from specimen to specimen. The tamper comprises eight tamping rods, each measuring 2.54 cm (1 in) thick and 1.77 cm (0.5 in) wide, all aligned to comprise a 5.08 cm (2 in) square. They will be made of a material (probably rubber) that conforms to ASTM standard C 109 5.6. Each finger rod is actuated by a small pneumatic cylinder. The robot itself will turn the tampers so that they will tamp in two directions. All of the cylinders have pressure and flow control to allow for tamping-force adjustment. The tampers will be mounted in an aluminum block body attached to one end of the end-effector.









Dimensions are estimated, not to be used as a blueprint

TxDOT/TSIC

Tamper Detail

Drawn P.F.M.	Date 9/30		
Approved S.S. Chen	9/30	8.5x11	Dwg No. 4.9
Design S.S. Chen	9/30	Scale NTS	Figure 4.9

REV A

10. Mixer, paddle and bowl

a) The mixer will be the model N-50 Mixer manufactured by the Hobart Corporation. The mixer is mounted onto a fixture that will raise and lower the mixer, and turn it ninety degrees in one fixed direction. This allows the paddle to rise high enough to clear the paddle cleaner and the mixing bowl before being lowered down into them.

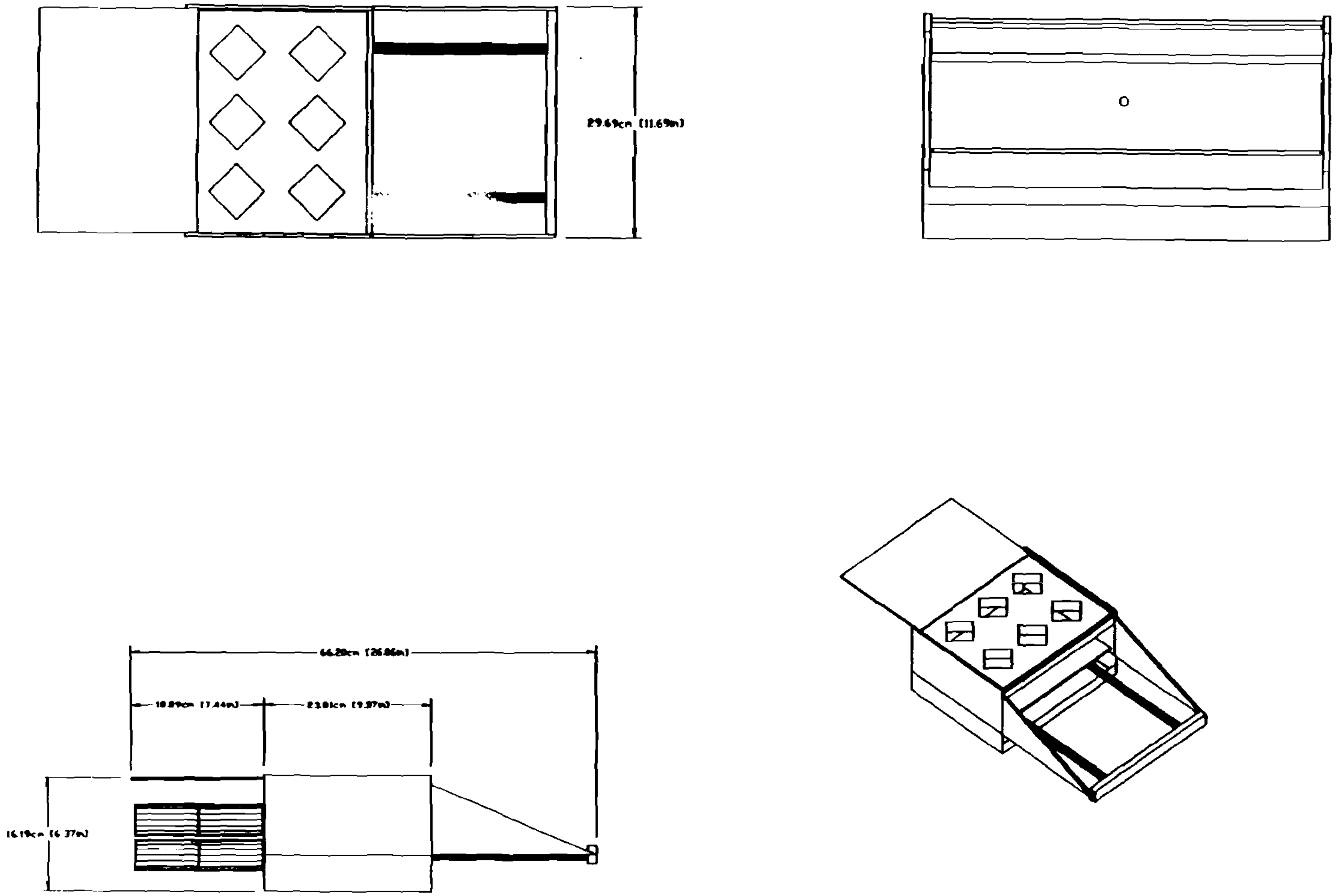
b) The paddle will be a modified, special stainless steel "B" flat beater, part No. 274688, manufactured by the Hobart Corporation.

c) The bowl will be the mixing bowl, part No. 78575-2, manufactured by the Hobart Corporation.

11. Mold housing (Refer to Figure 4.10)

The mold-housing will enclose the two molds and a 2.54 cm(1 in) thick guide on top of the molds. The guide has six openings through which the scooper deposits specific amounts of mix for the tamper to tamp. This guide will keep any excess mortar from spilling over the sides of the molds. Excess mortar from the molds will remain in the openings of the guide and be rinsed out after the two molds have been pulled out of the mold housing. There will be a washing system built within the mold housing unit to clean off excess mortar left behind after the two molds are pulled out. Spray nozzles will move back and forth inside the mold housing and spray highly pressured water throughout the interior of the mold housing from beneath. The residual mortar is washed down, into drain, by the traversing action of the water spray.

The two molds will be mounted on a tray that will slide in and out of the mold housing automatically. Once the tamping is finished, a side door will automatically open to let the tray out. The door will automatically close and the rinse cycle will begin. The automatic moving of the tray in and out of the mold housing will ensure that residual mix left in the mold housing will be immediately sprayed and washed down the drain. This will keep any mix from hardening on the inside of the mold housing. The mold housing will be constructed of aluminum.



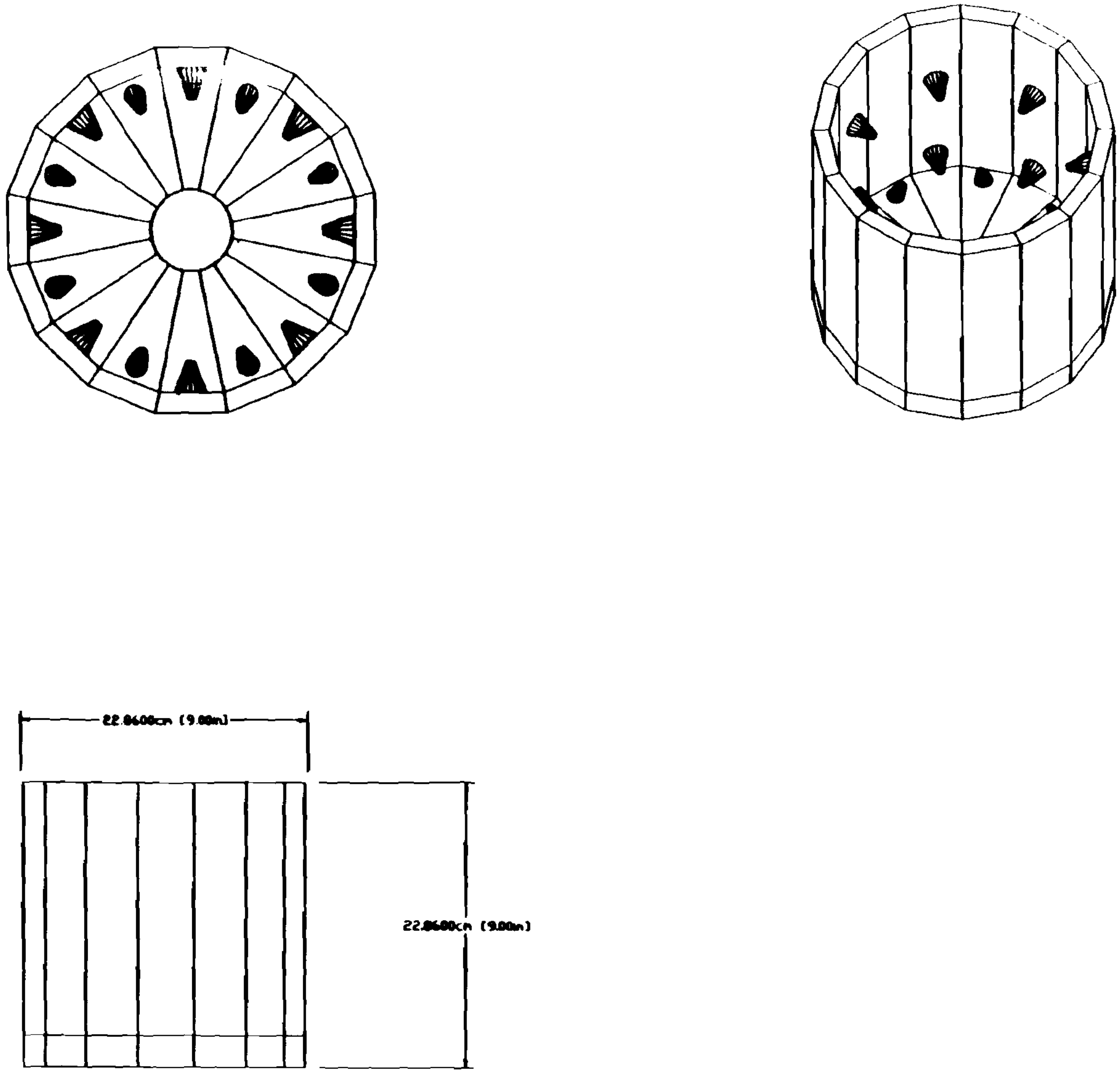
Dimensions are estimated, not to be used as a blueprint		TxDOT/TSTC	
		MOLD HOUSING	
Drawn P.F.M.	Date 9/30		
Approved S.S. Chan	9/30	8.5x11	Dwg No. 4.10
Design S.S. Chan	9/30	Scale NTS	Figure 4.10

12. Cleaning apparatus (Refer to Figures 4.11, 4.12 and 4.13)

The cleaners are very important to the product quality from the workcell because they ensure that mortar from a previous batch does not contaminate the batch being processed. Every mechanism that comes in contact with the cement or mortar must be thoroughly cleaned before it is reused. Three cleaners are used in this workcell.

a) Mixing bowl cleaner: The bowl cleaner is positioned below the mixing bowl. At the base of the bowl is a large, upright, central nozzle surrounded by eight smaller nozzles. After the mortar has been removed, the mixing bowl will be inverted and lowered down into the cleaner. The spray of the large central jet will follow the contour of the bowl, allowing water to reach all areas on the inside of the bowl. The smaller nozzles will also spray the sides of the bowl to help ensure thorough cleaning. To speed up the drying process, warm water or injected air will be used.

b) Paddle cleaner: The paddle cleaner is located next to the mixer bracket. It is a cylindrical bowl with small nozzles located on the inside pointing at the center. The mixer will be lifted, moved to this station, and lowered into the cleaner. When the paddle is lowered into the cleaner, the paddle will be activated to rotate the and high-pressure jets will spray water on the paddle from all directions to clean off the residual mortar. The lids will help as a splash guard to prevent water from getting onto other equipment.



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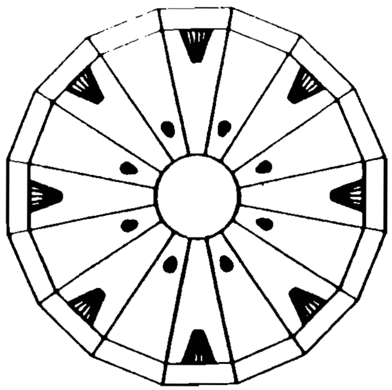
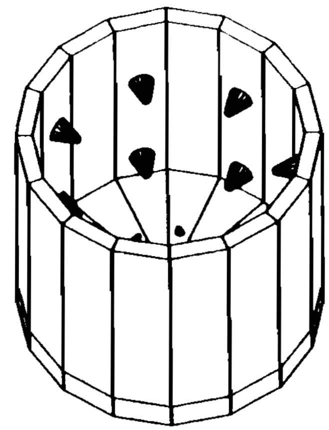
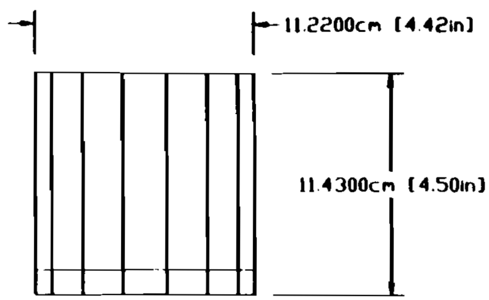
TxDOT/TSTC

Paddle Cleane

Drawn P.F.M.	Date 9/30	8.5x11	Dwg No 412
Approved S.S. Chen	9/30		
Design S.S. Chen	9/30	Scale NTS	Figure 4







Dimensions are estimated, not to be used as a blueprint

TxDOT/TSTC

End Effector Cleaner

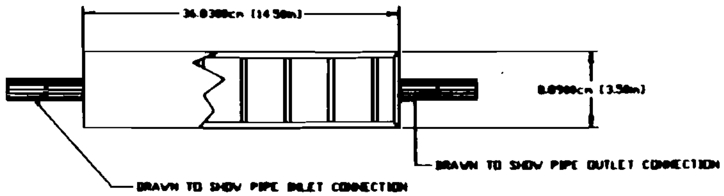
Drawn	Date	Size	Dwg No	Rev
P.F.M.	9/30	8.5x11	413	A

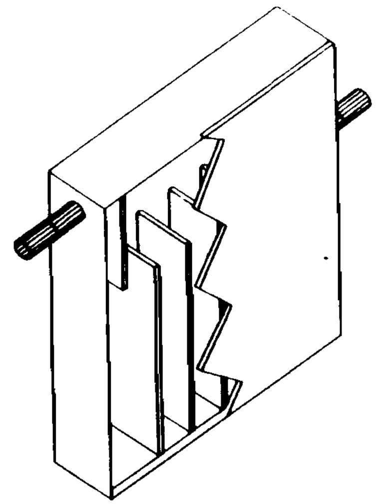
Approved: S.S. Chan	9/30	Scale NTS	Figure 413
Design: S.S. Chan	9/30		

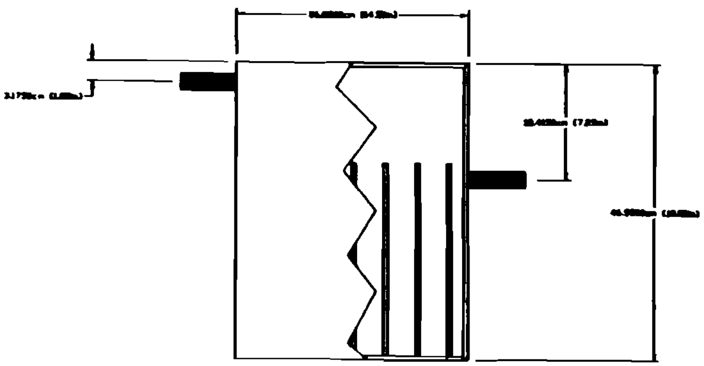
13. Septic system (Refer to Figure 4.14)

a) The septic tank works in a similar fashion to septic tanks found in many rural homes. Its sole function is to keep large masses of mortar from clogging the sewage system. The septic tank is a large, watertight, stainless-steel box. The bottom of the tank is lined with baffles. Each of these baffles will have to be filled before the water can flow to the next one. Heavier sediments will collect between the baffles, preventing the flow of sediments into the building's sewage system. At the end of each day depending on the usage, the septic system should be cleaned out. Cleaning of the septic system is done by simply flushing large amounts of water through the tank and occasionally scooping out waste.

b) The pipes are connected from the cleaners to the septic tank at 45 degrees or more in order to keep the cement residue flowing inside. All these pipes are made of PVC.







Dimensions are estimated not to be used as a blueprint

TxDOT/TSTC

Septic Tank

Drawn P.F.M.	Date 9/30
Approved S.S. Chen	9/30
Design S.S. Chen	9/30

8.5x11 | Dwg No 414 | REV A

Scale NTS | Figure 414

14. Air-conditioning unit

In this project, we assume that the workcell will be placed indoors, and we also confined the air-conditioned area inside the laboratory to an area of about 182.88 cm (6 ft) by 243.84 cm (8 ft). The workcell is enclosed by well-sealed plexiglass walls. It is estimated that a 4,000 BTU/hr air-conditioner will serve the purpose. There is a comparatively big saving in utility costs in operating this workcell.

After study, a self-contained air-conditioner unit, which contains a condenser, a motor compressor, an evaporator, a fan and controls, such as a room air-conditioner, should be able to serve the workcell area. The cost of this unit is in the seven-hundred-dollar to eight-hundred-dollar range.

Since the cleaners inside the workcell contain water, the relative humidity inside the workcell will be kept at 50% or higher while the temperature inside the cell will be kept at 23°C (73.4°F).

C) **Process Sequence**

The temperature of the surrounding environment is maintained between 20°C and 27.5°C (68°F and 81.5°F) and the temperature of the equipment used are within the above range at the time of the test. The temperature of the mixing water shall not vary from 23°C (73.4°F) by more than + 1.7°C (3°F). The relative humidity shall not be less than 50%.

The following is a list of the complete sequence of one batch mixing. This includes the measuring of sand and water, the mixing process, the scooping of the mortar, the packing and tamping of the mortar, and all the cleaning of parts that come in contact with the cement or mortar.

1. Starting position of all stations.

   a) The robot arm will be in the home position without power. This will allow the operator to safely pour the cement powder into the mixing bowl.

   b) The mixer will be positioned above the mixer cleaning station. This will allow the operator free access to the bowl without the mixer being in the way.

   c) Clean molds are placed on the tray and are ready to be automatically inserted into the mold housing.

   d) The READY indicator light on the operator's panel is on.

2. Preparation of cement sample and sand.

   a) The operator will manually measure the cement powder and pour it into the mixing bowl.

   b) The operator will manually measure the standard graded sand and pour it into the sand dispenser.

3. Starting the mixing process.

The operator stays outside the workcell area after he pours cement into the mixing bowl. He will press the 'START' button. The process cycle will now begin.

4. Mixing process.

a) Mixing	MIXER	SPEED	RUN TIME	TOTAL TIME
1. Power to mixer off.	OFF		0:00	0:00
2. Dry bowl in place.				
3. Add Water automatically				
4. Operator adds cement manually.				
AUTOMATED CYCLE STARTS:			0:00	0:00
5. Set speed switch to #1.		#1		
6. Turn on the power.	ON			
7. Mix for 30 seconds.			0:30	0:30
8. Dispense sand slowly over 30 seconds.			0:30	1:00
9. Stop mixer.	OFF			
10. Set speed switch to #2.		#2		
11. Turn on the power.	ON			
12. Mix for 30 seconds.			0:30	1:30
13. Stop mixer.	OFF			
14. Let it set for 15 seconds.			0:15	1:45
15. Cover bowl with lids.				
16. Let it set for 1 minute and 15 seconds.			1:15	3:00
17. Remove lids from bowl.				
18. Turn on mixer.	ON			
19. Mix for 1 minute.			1:00	4:00
20. Stop mixer.	OFF			
21. Let it set for 1 minute and 30 seconds.			1:30	5:30
22. Turn on mixer.	ON			
23. Mix for 15 seconds.			0:15	5:45
24. Stop mixer.	OFF			
TOTAL PROCESS TIME				5:45

b) After mixing, the mixer will be lifted and rotated 90 degrees to the right, and lowered into the paddle cleaning station. The water jets will be turned on to spray the excess mortar off the paddle. Once the cleaning time has elapsed, the mixer will be raised and will remain in this position until the start of the next process.

5. Scooping, tamping and cleaning of the end-effector.

a) The robot will move the scooper over the bowl to fetch one scoop. The scooper will hold approximately 73.74 cm^3 (4.5 in^3) of mortar.

b) Once the mortar has been obtained, the robot will move and position the scooper above the first mold opening. The scooper then moves in a small circular motion as the mix is ejected into the mold. This is to provide more even distribution of the mix inside the mold.

c) At this point, the robot will repeat steps a) and b) five more times. This will pack the six mold openings with approximately 1 in thick of mortar.

d) Now the robot end-effector will rotate 180 degrees to put the tamper in place. Then the tamping process will begin.

e) The tamper will position itself above the first opening and tamp each mold unit with a specific amount of force in the specific sequence as dictated by the ASTM standards.

f) Now the tamper will rotate 90 degrees and continue to tamp in the specified sequence and direction while still at the first mold opening.

g) At this point, the robot will repeat steps e) and f)five more times for the other five mold openings.

h) Once the first layer of mix has been pressed in and tamped, steps a) through g) will be repeated for the second layer of mix.

i) After the second layer of mix has been pressed in and tamped, the entire end-effector will be moved to the cleaning station where the scooper and tamper will be cleaned.

6. Removal and cleaning of the two molds.

a) Removal of the molds.

Once the tamping process has finished, the door on the mold housing will open and the tray containing the molds will slide out. Then the door on the mold housing will close. The molds are now ready to be removed, troweled, cleaned and placed in storage.

b) Washing of the mold housing.

Once the tray has emerged from under the mold housing and the door on the mold housing closed, the wash cycle will begin. A green 'MOLD READY' indicator light will turn on to show that the molds are ready for the operator and that the wash cycle of the mold housing has started.

c) Inserting clean molds for the next process cycle.

The operator will remove the filled molds and place two clean molds on the tray. After that, he presses the 'NEW MOLD' button and the tray will move into the mold housing. The door on the mold housing will close and now the molds are ready for the process cycle.

7. Cleaning of the paddle.

   a) Once the mixing process has finished, the paddle will be lifted, moved above the cleaning station, and lowered into the cleaner.

   b) Once the paddle has been washed, the paddle will be raised and will remain in this position until the next batch is ready for mixing.

8. Cleaning of the mixing bowl.

   a) Once the scooping process has finished, the mixing bowl will be inverted and lowered 5.08 cm to 7.62 cm (2 to 3 inches). Water jets will spray the inside of the bowl from beneath and clean the residual mortar from the bowl.

   b) Once the bowl has been washed, the bowl will be raised and will remain in this position until the next batch is ready for mixing.

9. Beginning the process again.

   Once a process cycle has finished, the 'READY' indicator light will be on. This is to indicate that all the apparatus at each station is in the correct position for another process cycle. Now the process may start again.

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V. STANDARD MODIFICATIONS

1. Paddle (Refer to Figures 5.1)

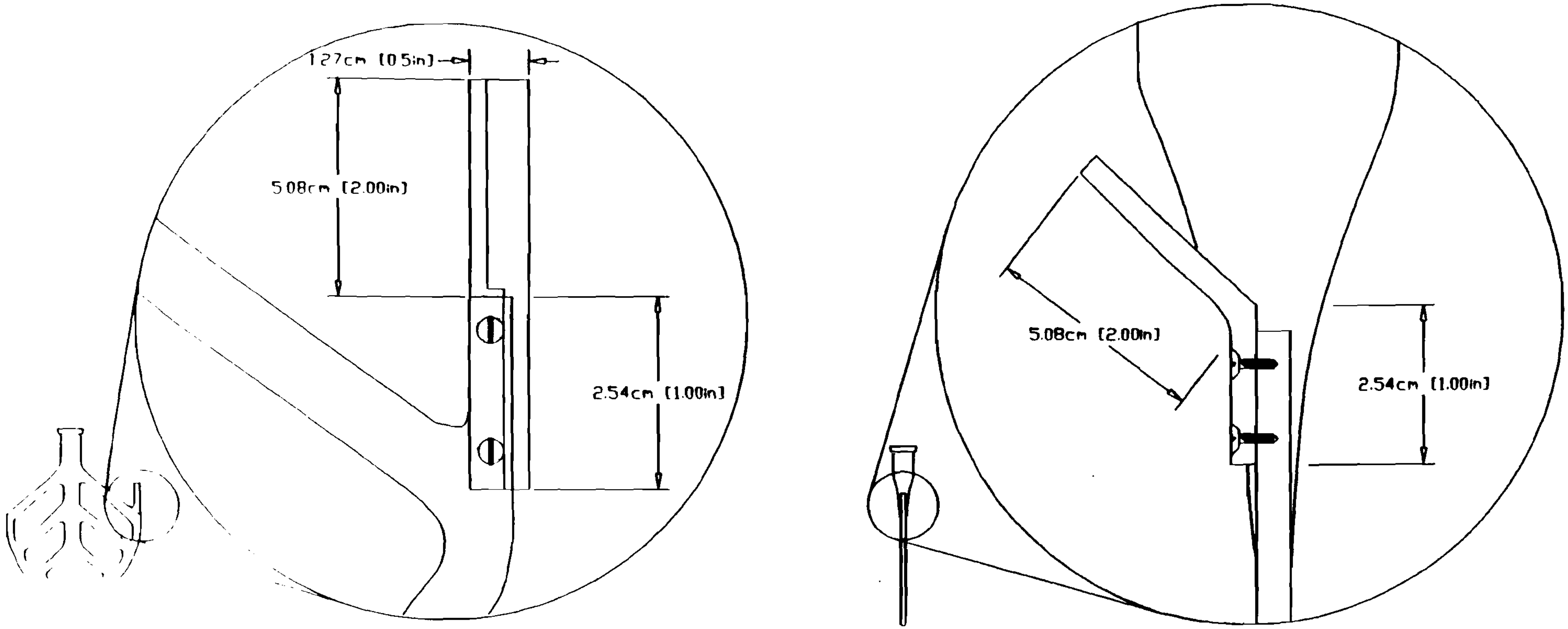
The paddle will be modified to include a small rubber strip which will be mounted on one side of the paddle. The small rubber strip will be bent at a 45 degree angle towards the direction that the paddle rotates (clockwise). With the paddle modified, the mortar on the sides of the bowl will be scraped down to the surface of the mortar.

This modification does away with the step for scraping down the bowl. With this modification, the mortar will constantly be scraped down to the proper level.

Since there is no alternative to the modification of the paddle, this change will have to be accepted by ASTM. The reason for this change is that there are design complications in trying to duplicate the scrape-down action of the scraping sequence required by ASTM. The paddle has been redesigned to avoid this complication and also improve on the scrape-down process.

The rubber used will be of a strong, durable type that will be non-absorbing and will not become brittle.

It is the conclusion of the TSTC research team that this modification will improve the scrape-down process and help keep the mortar at a constant level in the bowl.



Dimensions are estimated, not to be used as a blueprint.		TxDOT/TSTC	
		Paddle Modified	
Drawn P.F.M.	Date 9/30		
Approved S.S. Chan	9/30	8.5x11	Dwg. No 5.1 · REV A
Design R.L.M.	9/30	Scale NTS	Figure 5.1

2. Mixer/Mixer bracket (Refer to Figure 5.2)

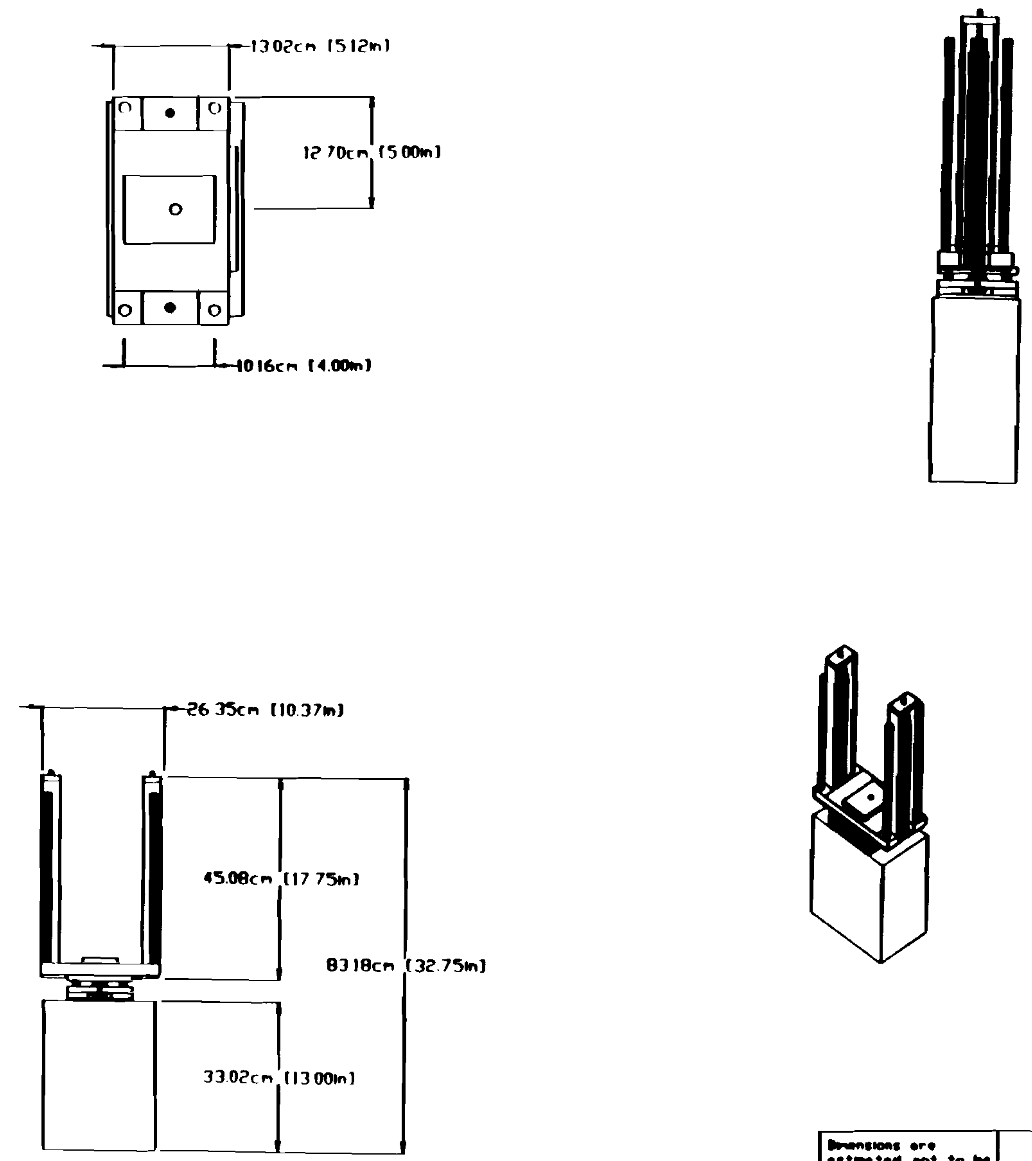
The mixer will be modified from the standard mixer to include a modified adaptor attached to the speed-control knob, an externally controlled on/off switch, and a redesigned base.

Speed control can be done in one of two ways: using a two-speed electric motor or using an adaptor attached to the speed-control knob to change the speed mechanically. The latter of the two is preferred since it conforms more to ASTM standard C 305-82 3.1.

The externally controlled on/off switch will be a simple power relay controlled by the workcell controller.

The redesigned base will enable the paddle to move out of the mixing bowl to the paddle cleaner. The base will be able to rotate 180 degrees towards the cleaner and be lifted high enough to clear the bowl and the paddle leaner. It will be of sturdy construction to withstand the constant vibration and torsional forces occurring during the mixing of the mortar.

All of the actuators will be pneumatic. Pneumatic actuators are clean, reliable and of relatively low cost compared to other types of actuators.



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TxDOT/TSTC

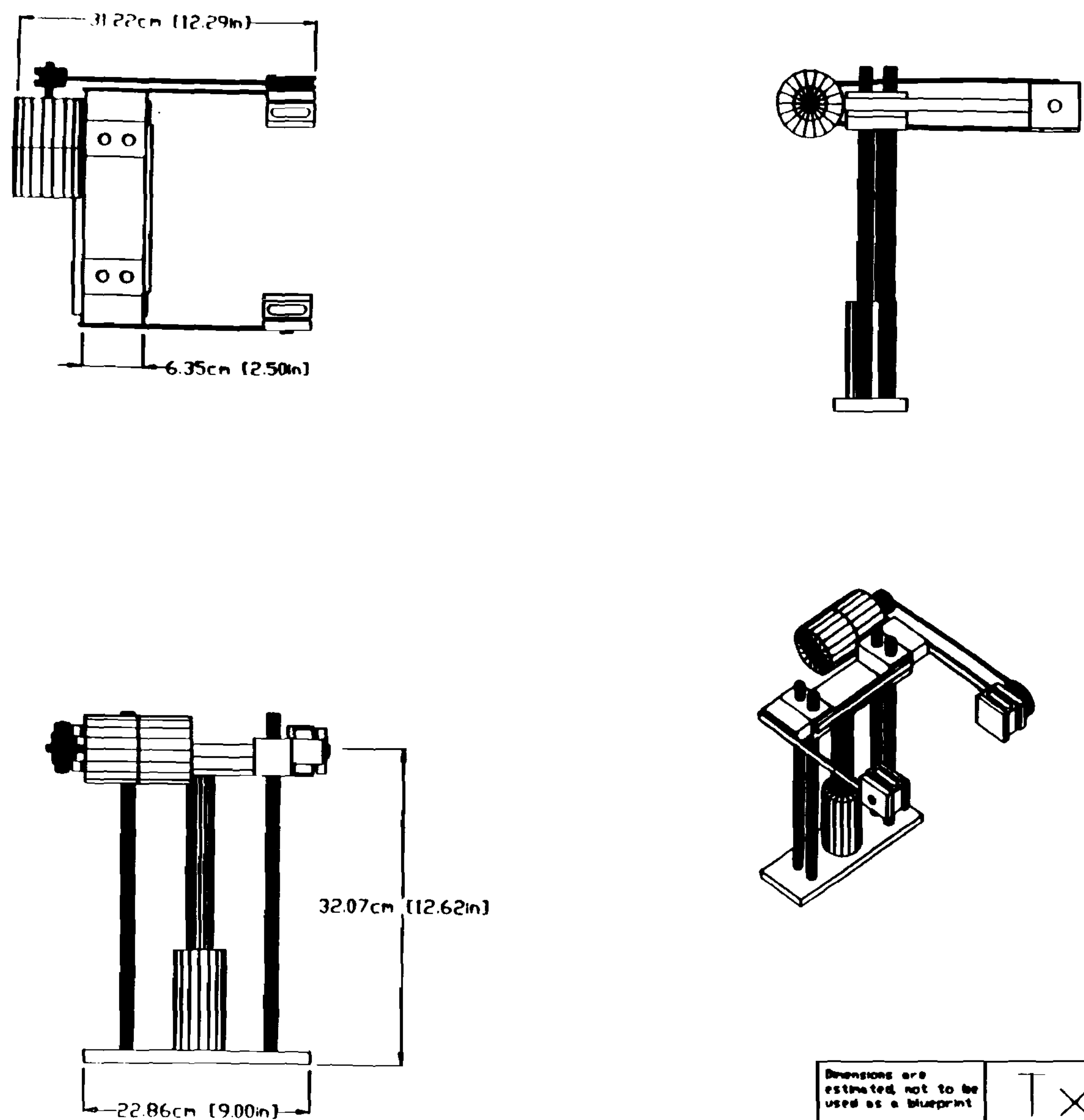
Mixer Bracket

Drawn P.F.M.	Date 9/30	Size 8.5x11	Dwg No. 5.2 REV A
Approved S.S. Chen	9/30	Scale NTS	Figure 5.2
Design S.S. Chen	9/30		

3. Bowl/Bowl bracket (Refer to Figure 5.3)

The Bowl will be the standard bowl as outlined in ASTM standard C 305-82 3.3; but the bracket will have to be modified to function in this automated environment. The bowl bracket will be modified to be attached to an apparatus to enable it to move up and down as well as be inverted. These movements are required to allow the bowl to be cleaned by the cleaner below.

Like the mixer base, the bowl bracket will have to be made extremely sturdy so that it can withstand the vibration and torsion occurring during the mixing process. The mixing bowl bracket will have two pneumatic actuators: one will lift the bowl while the other will rotate it. These actuators will be controlled by the workcell controller.

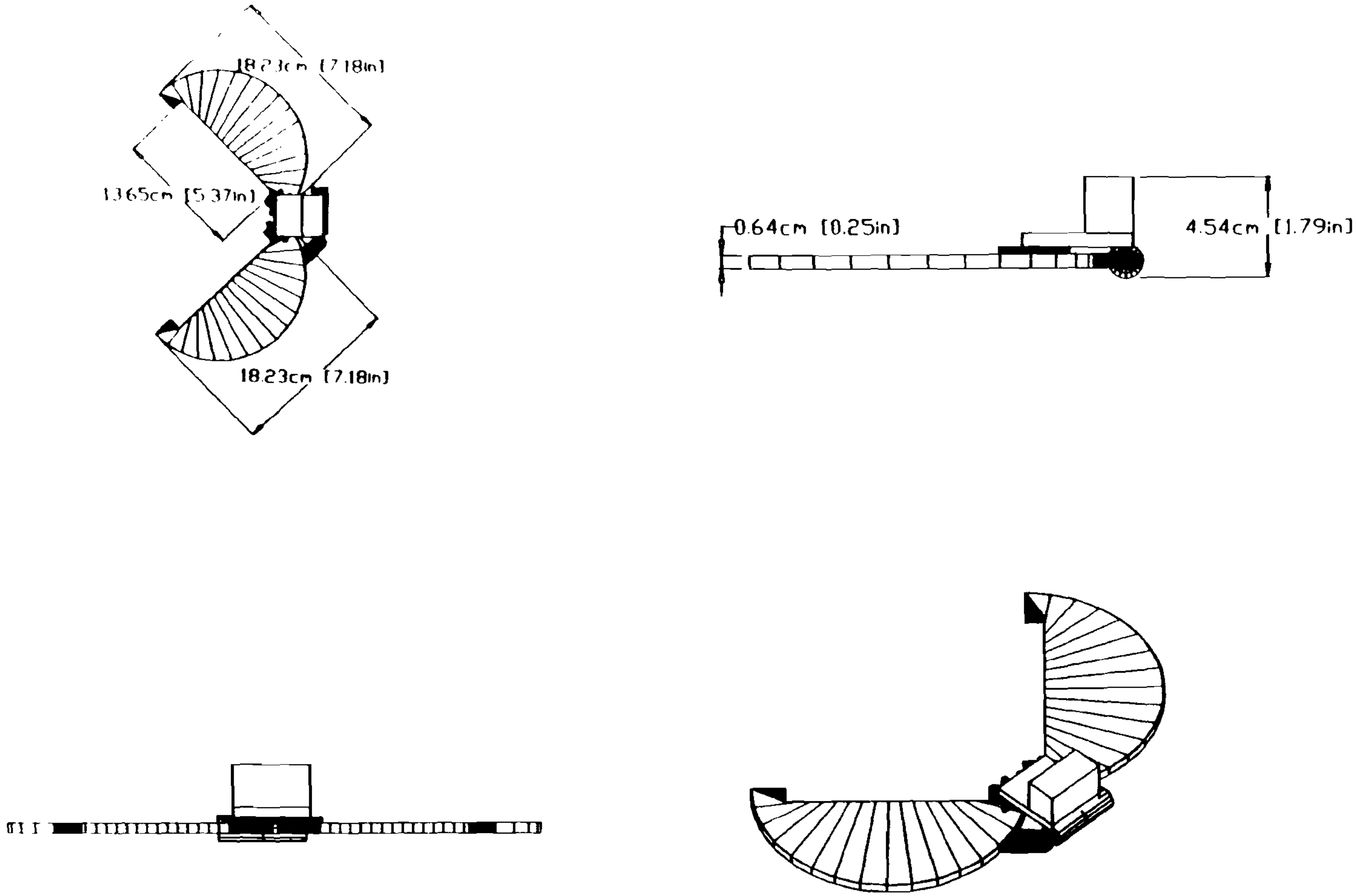


Dimensions are estimated, not to be used as a blueprint	TxDOT/TSTC
	Bowl Bracket

Drawn P.E.M.	Date 9/30	8.5x11	Dwg No 5.3	REV A
Approved S.S. Chan	9/30	Scale NTS		Figure 5.3
Design S.S. Chan	9/30			

4. Bowl Cover (Refer to Figure 5.4)

The ASTM standards require the bowl to be covered for a specific period of time at the middle of the mixing process. Using the standard cover, which consists of two stainless steel lids, the operator has to visually locate the paddle's stopping position before he adjusts the lids to cover up the mixing bowl. As a result, it would be unfeasible to automate the task because the machine has no vision capability to know where the paddle stops, and the lids may collide with the paddle. So, a modified flexible rubber cover will be used. It will comprise of two semi-circular lids that will close around the paddle. The lids will be activated by a small pneumatic cylinder and be controlled by the robot controller. Slots on the inner edges of both lids have to be made so that no matter where the paddle ends up, it will not collide with the lids. The lids will be mounted near the mixer base and behind the paddle.



Dimensions are estimated, not to be used as a blueprint		TxDOT/TSTC	
Drawn P.F.M.	Date 9/30	Bowl Cover	
Approved S.S. Chan	9/30	Size 8.5x11	Dwg No 5.4 / Rev A
Design S.S. Chan	9/30	Scale NTS	Figure 5.4

VI. CONCLUSION

The purpose of this feasibility study is to design a turnkey automation system which performs cement mixing, filling, tamping, data processing and storing, and printing of the process report.

While we try our best to create mechanisms that work well, we also have ASTM standards to comply with. Actually, we have better designs in mind, but the necessity of compliance with ASTM standards has rendered them unfeasible. This project is the first attempt at applying state-of-the-art technology while trying to comply with national standards that are more suited to manual systems. Without recourse, we have had to make use of modified versions of mechanisms specified in the ASTM standards. Modifications are crucial to the success of this project. Revisions to the ASTM standards will have to be seriously considered if new technology is to be adopted for future progress.

This feasibility study stresses the consistency and the cost effectiveness of the process. It has identified the varying factors in the process, and has attempted to automate it in order to reduce the variation. If any replacement parts are required, the system has to be recalibrated before operation commences. This is to ensure consistent performance of the workcell. The advantages of these robotic applications can also be expanded to other testing procedures.

VIII. ACKNOWLEDGEMENT

The research team of the Department of Automation/Robotics, Texas State Technical College-Sweetwater, would like to thank Ms. Katherine H. Hargett, Director of Testing and Measurement, Texas Department of Transporation, for offering the opportunity to conduct this feasibility study and the subsequent construction of the first-of-its-kind robotic workcell. We also need to thank Mr. Paul Krugler and Mr. Tommy Etheredge of Texas DOT for their detailed assistance during the study. Under the auspices of Dr. Clay Johnson, President of TSTC-Sweetwater, and Dr. Robert Musgrove, Dean of Instructions of TSTC-Sweetwater, the research team members have been inspired to conduct this project with confidence and enthusiasm. Finally, we greatly appreciate our secretary, Ms. Judy Romine, for her tireless efforts.

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