San Onofre Nuclear Generating Station, Unit 1

MASONRY WALL TEST PROGRAM

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A. PURPOSE

As a part of the Systematic Evaluation Program Topic III-6, Seismic Design Considerations, the masonry walls at San Onofre, Unit 1 were evaluated using a nonlinear inelastic time history analysis. This analysis was performed by Computech Engineering Services, Inc. (CES) and is presented in References 1 through 4. The main objective of the test program is to demonstrate the overall conservatism of the analysis results. Although many walls exhibited considerable inelastic response, all were within the limits set forth in the acceptance criteria. The NRC staff indicated in References 5 and 6 that the methodology could not be accepted without additional confirmatory testing. Details of a test program were discussed in a meeting on May 11 through 13, 1982.

The main objective of this test program is to demonstrate the overall conservatism of the analysis methodology and not to proof test the walls. This report provides a detailed description of the scope and schedule for a masonry wall test program to resolve the NRC's concerns.

B. DESCRIPTION OF TEST SPECIMENS

In order to achieve the stated objective, the wall sections chosen for testing are based on those wall sections existing at San Onofre Unit 1 that proved to be the most critical in the analysis performed by CES. Each test panel will be constructed of 8 inch thick concrete masonry block (8" x 8" x 16" units) and grade 40 reinforcing bars. All panels will be single wythe. Three wall sections have been selected for testing. Their characteristics will be as follows:

1. Panel Type 1 is to be 23'-10" high, excluding base, with reinforcing equivalent to #7 bars at 32 inches as vertical reinforcement and #5 bars at 48 inches as horizontal reinforcement. Three test samples will be constructed.

   This panel type corresponds in height and reinforcement to Fuel Storage Building walls FB1 through FB7. In addition, the Ventilation Equipment Building walls VB1 through VB4 have identical reinforcing, but these walls are approximately three feet shorter than the test panels.

   Walls FB1 through FB7 are the heaviest reinforced masonry walls at San Onofre Unit 1 and are also the tallest. Furthermore, they are the only masonry walls not founded on grade and as such, their input motions will have in-structure amplification in excess of any other masonry walls found at SONGS-1.

2. Panel Type 2 is to be 16'-5" high, excluding base, with reinforcing equivalent to #5 bars at 48" as vertical reinforcement and #5 bars at 48" as horizontal reinforcement. Two test samples will be constructed.

   This panel type corresponds in height and reinforcing to Auxiliary Building walls SB1a, SB2, SB4 and SB7. Walls SB1, SB3, SB5 and SB6 have identical reinforcing but are approximately seven feet shorter. Therefore, the test specimens represent the tallest masonry walls having the lowest amount of reinforcing of any masonry wall at San Onofre Unit 1.

3. Panel Type 3 is to be 21'-4" high, excluding base, with reinforcing equivalent to #5 bars at 32 inches as vertical reinforcement and #5 bars at 48 inches as horizontal reinforcement. Two test panels will be constructed.

   This panel type corresponds to the Turbine Building walls where the dynamic response in CES's analysis was the highest. This panel is typical of walls TB1a, TB5, TB6, TB7a, TB9, TB10 and TB11. These walls are approximately six feet higher than any of the other Turbine Building walls.

Based on seismic considerations, the configurations of the chosen panel types represent the governing masonry walls at San Onofre Unit 1. Due to their combinations of heights, reinforcing and location the analysis results indicated that these wall configurations would exhibit the greatest seismic responses during a DBE.

Each panel is to be approximately 8 feet long. Practical considerations of space, lifting capacity and the driving capacity of the actuators set a practical upper bound of approximately eight feet on the wall length. A lower bound on the wall length is set by the desire to have at least three vertical bars in each test panel. With a 32 inch spacing this requires an eight foot length to simulate a spacing of #5 bars spaced at 32 inches. Panel type 2 calls for #5 vertical bars spaced at 48 inches. This would result in only 2-#5 bars over the eight foot length. In this case 3-#4 bars will be used rather than 2-#5 bars. This provides the panel with an equivalent amount of reinforcing, based on area of steel per foot of wall. Similar adjustments in reinforcing may be considered for the other walls to provide equivalent reinforcement.

The methods and materials used to construct the walls shall be as close as is reasonably possible to those used in the construction of the walls at San Onofre Unit 1.

In order to verify the similarity of materials between the test panels and the insitu walls, each panel will have specimens of grout, steel, mortar and block which will be tested (see Section E). The results of this testing will be utilized in assessing any differences between the test panels and the insitu walls.

The top and bottom anchorages of the test panel will simulate in type and spacing the actual supporting systems of the walls. Where appropriate, dummy weights and/or equipment typical of that found attached to masonry walls at San Onofre Unit 1 will be attached to the test panels. Where this equipment is attached to the test panel, anchorages to the masonry will also be typical of those found at the site.

C. DESCRIPTION OF TEST FACILITY

The tests will be performed at the structural laboratories of the Earthquake Engineering Research Center, University of California, Berkeley. The test setup, shown in Figure 1, is similar to the one currently used for an ongoing in-plane shear test program. The test setup will consist of four adjacent reaction frames (A-frames) as shown in Figure 1 and two MTS actuators located towards the top and bottom of the reaction frames as shown in Figure 2. The test walls will be placed on Thomson Dual Roundway Bearings to allow the walls to move freely with minimal friction force. The bearings have a coefficient of friction equal to .007. The test walls will be oriented normal to the actuators.

The actuators are capable of developing a maximum dynamic load of 75 kips using a hydraulic pressure of 3000 psi for a relatively short time. A nominal use of the hydraulic system requires a hydraulic pressure of 2500 psi thus reducing the dynamic load to 62.5 kips. The maximum stroke of the actuators is $\pm$ 6 inches, the maximum piston velocity is 26 in/sec and the flow capacity of the servovalves is 200 gal/min. The actuators are controlled by a displacement command signal in either of two fashions:

1. The actuators follow a prescribed displacement pattern which can be any earthquake time history, sine wave, step function, etc. This is the most common test method and will be used for this test.

2. The actuators displace until a predetermined resisting force is achieved and then displace further in either direction until a new magnitude of resisting force is achieved. This type of displacement control provides limited displacement patterns as the actual displacement time history is dependent on the structure being tested and is not precisely known beforehand.

The operational capabilities of the actuators are limited by the above-mentioned force, velocity and displacement capacities and also by a frequency limitation of about 5 Hz for sinusoidal loads.

No major modifications are required to the existing individual reaction frames. Two stiff cross beams will be constructed between the reaction frames in order that the four test frames will perform together. The actuators will be bolted to these cross beams and located as shown in Figure 2.

D. TEST INPUTS

The test input motions will be selected by reviewing the analyses results obtained by CES (see References 3 and 4) and identifying those motions that produced the highest response levels in the subject walls. Input motions will then be selected for each of the test panels to subject them to the levels of response similar to those shown in the analyses.

The actuator system used in the test program will consist of two actuators oriented perpendicular to the test panel. There will be one actuator at the top and one at the bottom of each test panel. In this configuration the actuators will subject the wall to horizontal out-of-plane excitation. The actuators will be controlled through a displacement demand signal, as opposed to a force demand signal. For this reason, the displacement time histories of the selected earthquake motions will be used as input signals to drive the actuators. At this time it is anticipated that the two actuators will be controlled by the same signal (i.e. input to the top and bottom of the panel will be the same). However, a study is currently underway to determine the feasibility of controlling the actuators with separate signals. If this study shows that this capability can be developed in a timely manner, then this capability will be incorporated into the test program.

It is anticipated that the actuator system will reasonably be able to reproduce the displacement time histories which are consistent with the CES analysis results for each of the selected test panel types.

However, the actuators have certain operational limitations, as described in Section C. These limitations are: a ± 6 inches limit on the displacement (stroke), a ± 26 in/sec limit on the velocity and an acceleration limit determined by the actuator's maximum achievable dynamic force, 75 kips, coupled with the specimen weight. As the test specimen is not a rigid mass but a dynamic object whose impedance varies with frequency, the peak of acceleration achievable at any frequency depends to some extent on the dynamics of the test panel being driven. The analyses performed by CES indicate that the walls respond in the low frequency high displacement region of the earthquake motions. In order to meet the displacement limitations of the actuators some of the very low frequency ranges of these motions will require filtering.

The high frequency region of response is of little interest as the panels will respond in a relatively low frequency region. Since the high frequency region of response accounts for much of the energy demand on the actuators, it may be necessary to filter some of the high frequency signals in order to have the available energy concentrated into the frequency ranges of interest.

Therefore, the response of the actuators outside of the frequency ranges of interest may not match exactly the spectra obtained from the analysis results. However, every effort will be made to achieve input levels in those frequency ranges of interest consistent with those used in the analyses.

E. DATA TO BE MEASURED

There will be three groups of tests performed, namely material property tests, low level dynamic response tests and high level dynamic response tests. The following addresses the data to be measured in each test.

1.0 Material Property Tests

1.1 Grout and Mortar.

For each panel a minimum of nine cylinder samples will be constructed concurrent with the construction of the panel of both the grout and mortar. Three cylinders of grout and three cylinders of mortar will be tested at (1) seven days, (2) 28 days following panel construction and (3) within 48 hours of the dynamic test of the panel. These cylinder tests will conform to ASTM C91 and ASTM C109-75.

1.2 Block and Prism Specimens.

A minimum of three samples of block and three prisms will be tested for each panel. The prism samples will be constructed at the same time and with the same materials as the panels they represent. The block and prism tests will take place within 48 hours of the dynamic test of the panels for which the blocks and prisms are representative. These tests will conform to ASTM E 447-74 and ASTM C 140-75.

1.3 Stress-Strain Properties of Reinforcing Bar.

A minimum of two specimens of rebar will be tested for each panel to determine the stress and strain characteristics of the rebar. These tests shall be performed in accordance with ASTM A 370-75.

2.0 Low Level Dynamic Response Tests

Snapback testing will be utilized to evaluate the damping corresponding to the uncracked and the cracked states of the test panel. This will involve statically displacing the panels, letting them vibrate freely and measuring the panel deflections by potentiometers. Damping will then be determined by the logarithmic decay method following standard procedures. In addition, following the high level testing of the panels an additional snapback test will be performed on one panel to determine the damping of a fully cracked wall for low input levels.

3.0 High Level Dynamic Response Tests

3.1 Deflection of the Test Panels.

Potentiometers will be used to measure the out-of-plane deflections of the panels during the testing. The potentiometers will be concentrated in the mid-height area of the wall since it is this area where the response is expected to be critical. The potentiometer locations are shown in Figure 3.

3.2 Curvature of the Test Panels.

The curvature of the test panels will be measured by attaching small studs to the panels. These studs will be oriented in a vertical line such that a LVDT may be oriented vertically when attached to two studs. Each LVDT will then be used to calculate vertical displacements between two stud locations. The curvature will then be calculated from these relative displacements.

The attachment studs will be spaced at eight inches over a seven foot length of the panel where yielding of the rebar is anticipated. Measurements will be taken from both sides (faces) of the panel. The locations of the attachment studs are shown in Figure 4.

3.3 The Acceleration Response of the Test Panels.

Accelerometers will be used to measure the acceleration response of the panels. The purpose of these measurements is mainly to measure the dynamic input to which the wall is actually subjected. The location of these accelerometers is shown in Figure 5.

3.4 Rebar Strains.

The reinforcement strains will not be directly measured during the tests. The rebar will be marked at one inch intervals over the central half of the bar prior to construction of the panels. Upon completion of the tests, the distance between the initial one inch marks will be measured and the permanent strain along the yielded region will be determined.

F. TESTING PROCEDURES AND SEQUENCE

The intent of this program is to assure that at least two samples of panel type 1 and one sample each of panel types 2 and 3 are successfully tested. Due to the size of the specimens, complexity of testing and the type and extent of the nonlinearities expected, back-up test samples will be constructed. The back-up panels will be used if the first test samples are lost due to unforeseen circumstances. Otherwise they will be used for tests 3, 5 and 7 as subsequently discussed if they are not needed for completion of Test 1,2,4 and 6.

In general, testing will consist of both low level snap-back and full intensity dynamic testing. Snap-back testing will measure the low level damping exhibited by the panel in three different states. These states are (1) uncracked, (2) cracked, before rebar yielding and (3) cracked, after rebar yielding. The uncracked low-level damping will be obtained prior to the full intensity dynamic testing and will be performed on the panel prior to any other loading. The cracked low-level damping before rebar yielding will also be performed prior to the full intensity test. However, the wall must be pre-cracked through the application of a low intensity input or another convenient means. A cracked low level damping test with the rebar yielded (after the full intensity tests) with the wall in its fully degraded state is also intended.

The full intensity dynamic tests are intended to measure various aspects of the walls inelastic response under severe dynamic loading.

These responses, once obtained, can then be utilized to verify the conservatism of the nonlinear analysis methodology presented in References 1 through 4. The full intensity dynamic test is not intended to be a direct proof test of the walls themselves, but will subject the walls, through the actuators, to seismic input levels consistent with those expected on the insitu walls under Design Basis Earthquake loading.

The sequence of testing is shown in Table 1 and is described as follows:

Test 1 - This test will be performed on a type 1 panel and will consist of three separate activities. The initial activity will consist of a snap-back test of sufficiently low level to ensure no cracking occurs. Upon completion of the snap-back test, the panel will be subjected to the full intensity dynamic test. Following the full intensity test another snap-back test will be performed on the panel in its fully degraded condition.

Test 2 - This test will also be performed on a type 1 panel. The wall panel will be subjected to a low level input high enough to ensure cracking. At this stage the test will begin with a snap-back test of sufficiently low level to ensure no yielding of the reinforcing steel occurs. Upon completion of the snap-back test, the panel will be subjected to the full intensity dynamic test.

Test 3 - Test 3 will be performed only if a type 1 panel is available after the useful completion of Tests 1 and 2. If this occurs Test 3 will consist of two activities. The initial activity will consist of a snap-back test of sufficiently low level to ensure no cracking occurs. Upon completion of the snap-back test, the panel will be subjected to the full intensity dynamic test.

Test 4 - This test will be performed on a type 2 panel. The activities will be identical to those identified for Test 3.

Test 5 - Test 5 will only be performed if a type 2 panel is available after the useful completion of Test 4. The activities for this test will be identical to those identified for Test 2.

Test 6 - Test 6 will be performed on a type 3 panel. The activities to be performed will be identical to those identified for Test 3.

Test 7 - Test 7 will only be performed if a type 3 panel is available upon the useful completion of Test 6. The activities for this test will be identical to those identified for Test 2.

As shown in Table 1 and stated above, Tests 3, 5 and 7 will be performed only if the respective panel types are available. Tests 1, 2, 4 and 6 will take priority over 3, 5 and 7.

TABLE 1

Test Number	Panel Type	Snap-back Test (No Cracking)	Snap-back Test (Pre-Cracked)	Full Intensity Dynamic Test	Snap-back Test (Post-Full Intensity Test)
Test 1	Type 1	X		X	X
Test 2	Type 1		X	X	
Test 3*	Type 1	X		X	
Test 4	Type 2	X		X	
Test 5*	Type 2		X	X	
Test 6	Type 3	X		X	
Test 7*	Type 3		X	X	

*Tests are dependent on test panel availability. If panels are damaged or Tests 1, 2, 4 or 6 must be rerun for any reason, then Tests 3, 5 or 7 will not be run.

G. TEST REPORTS

There will be three reports prepared covering the various phases of the test program. The contents of the reports are described below.

1.0 Report on Expected Test Responses.

Prior to the commencement of the testing of the panels, analyses will be performed to determine the expected test responses of each panel type. The parameters of importance that influence the response levels are the length of yielding rebar, tensile strength of mortar and grout core, damping, stiffness of uncracked section and boundary conditions. In pre-test analyses, the panel responses will be evaluated using the best estimates of the aforementioned paramaters rather than the conservative estimates which were previously used in the analyses of References 1 through 4. The input to the models will be the best estimate of the desired time-history input.

2.0 Report on Reduction and Evaluation of Test Data

This report will present the final methods and results and the manner in which the raw data was reduced. Included will be the following.

2.1 Detailed description of the test setup and its characteristics.

2.2 Development of the desired test inputs and a comparison of the desired and achieved input motions.

2.3 Strength characteristics of the grout and mortar for each panel.

2.4 Strength characteristics of the block and prism specimens for each panel.

2.5 Stress-strain properties of the rebar for each panel.

2.6 Low level damping exhibited during each of the snap-back tests.

2.7 Full intensity test data (directly measured). During the full scale dynamic testing of the test panels there will be approximately 40 channels of measured data. For each channel the maximum positive and negative values will be determined together with the time of occurrence. The following data will be obtained from four different measuring devices:

2.7.1 Deflections

a. Deflection profiles of the wall for the time periods during the testing when the maximum positive and negative displacements at the center of the wall are reached.

b. Selected time histories of each displacement channel will be plotted.

c. Relative time histories at the top and center of the wall with respect to the base of the wall will be plotted.

2.7.2 Curvature

a. The curvature between each of the points will be calculated at selected instants of time. The times selected will correspond to those in item a, section 2.7.1.

b. Time history curvature plots of selected channels will be presented.

2.7.3 Accelerations

a. Response spectra will be plotted for each of the accelerometers.

b. Time history plots of each channel will be presented.

2.7.4 Steel Strains

The final permanent steel strains will be obtained for at least one of the bars for each panel. The strains will be calculated from the total extensions between the one inch markings on the rebar following its removal from the test panel.

2.8 Full intensity test data (calculated or derived). Based on the data measured directly the following information will be derived, calculated or assessed:

2.8.1 The length of rebar which yielded.

2.8.2 The strain in the masonry face-shell.

2.9 Observations and Conclusions.

3.0 <u>Report on Application of Test Results on Analysis of Masonry Walls at San Onofre Unit 1</u>

This report will assess the conservatism of the analysis methodology presented in References 1 through 4 based on the results of the test data collected. The report will present a comparison of the test results and the analysis results for the key parameters of the walls response. The key parameters of response are the mid-span deflections, maximum rebar strains and masonry face shell stresses.

If the test results indicate that the key parameters obtained from the analysis are conservative, the analysis will be considered verified. If the test results indicate that one or more of the response parameters obtained from the analysis was not conservative, an assessment will be made as to the validity of the test results. If the test results are valid, the cause for the difference will be determined and the significance will be assessed with relation to the San Onofre Unit 1 masonry walls.

H. TEST SCHEDULE

It is anticipated that the testing will be complete by December 31, 1982. Compilation, reduction and preparation of the test reports is scheduled to be complete by March 1, 1983. Recognizing these milestone dates, a test schedule is presented in Figure 6.

I. REFERENCES

1. Computech Engineering Services, Inc., "San Onofre Nuclear Generating Station Unit 1, Seismic Evaluation of Reinforced Concrete Masonry Walls, Volume 1: Criteria", forwarded by letter from K. P. Baskin to D. M. Crutchfield dated January 15, 1982.

2. Computech Engineering Services, Inc., "San Onofre Nuclear Generating Station Unit 1, Seismic Evaluation of Reinforced Concrete Masonry Walls, Volume 2: Analysis Methodology", forwarded by letter from K. P. Baskin to D. M. Crutchfield dated January 11, 1982.

3. Computech Engineering Services, Inc., "San Onofre Nuclear Generating Station Unit 1, Seismic Evaluation of Reinforced Concrete Masonry Walls, Volume 3: Masonry Wall Evaluation", forwarded by letter from K. P. Baskin to D. M. Crutchfield dated January 11, 1982.

4. Computech Engineering Services, Inc., "San Onofre Nuclear Generating Station Unit 1, Seismic Evaluation of Reinforced Concrete Masonry Walls, Volume 4: Fuel Storage Building", submitted by letter from K. P. Baskin to D. M. Crutchfield dated April 30, 1982.

5. NRC letter from W. A. Paulson to R. Dietch dated February 17, 1982.

6. NRC letter from D. M. Crutchfield to R. Dietch dated April 29, 1982.

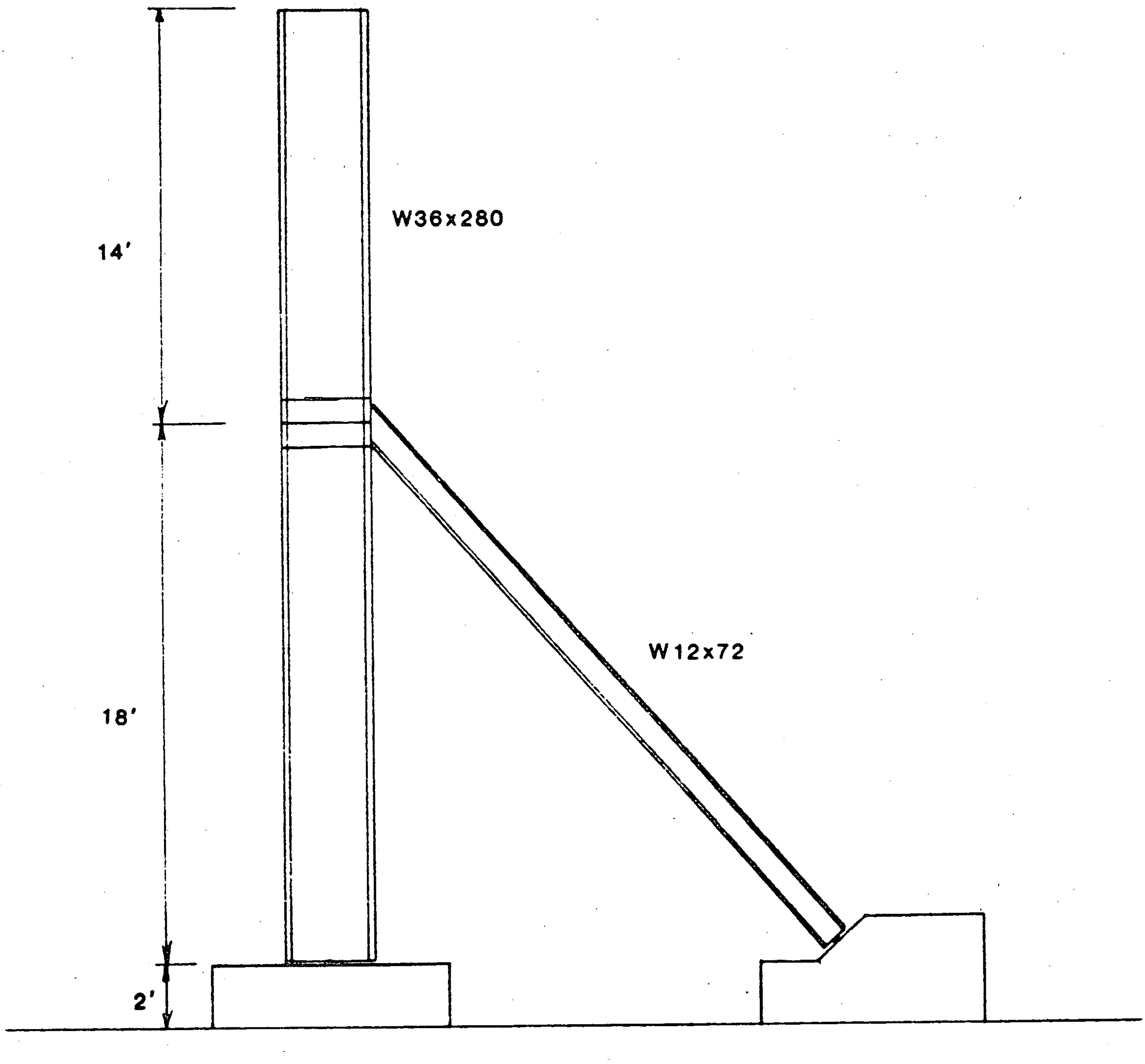


Figure 1 Reaction frame

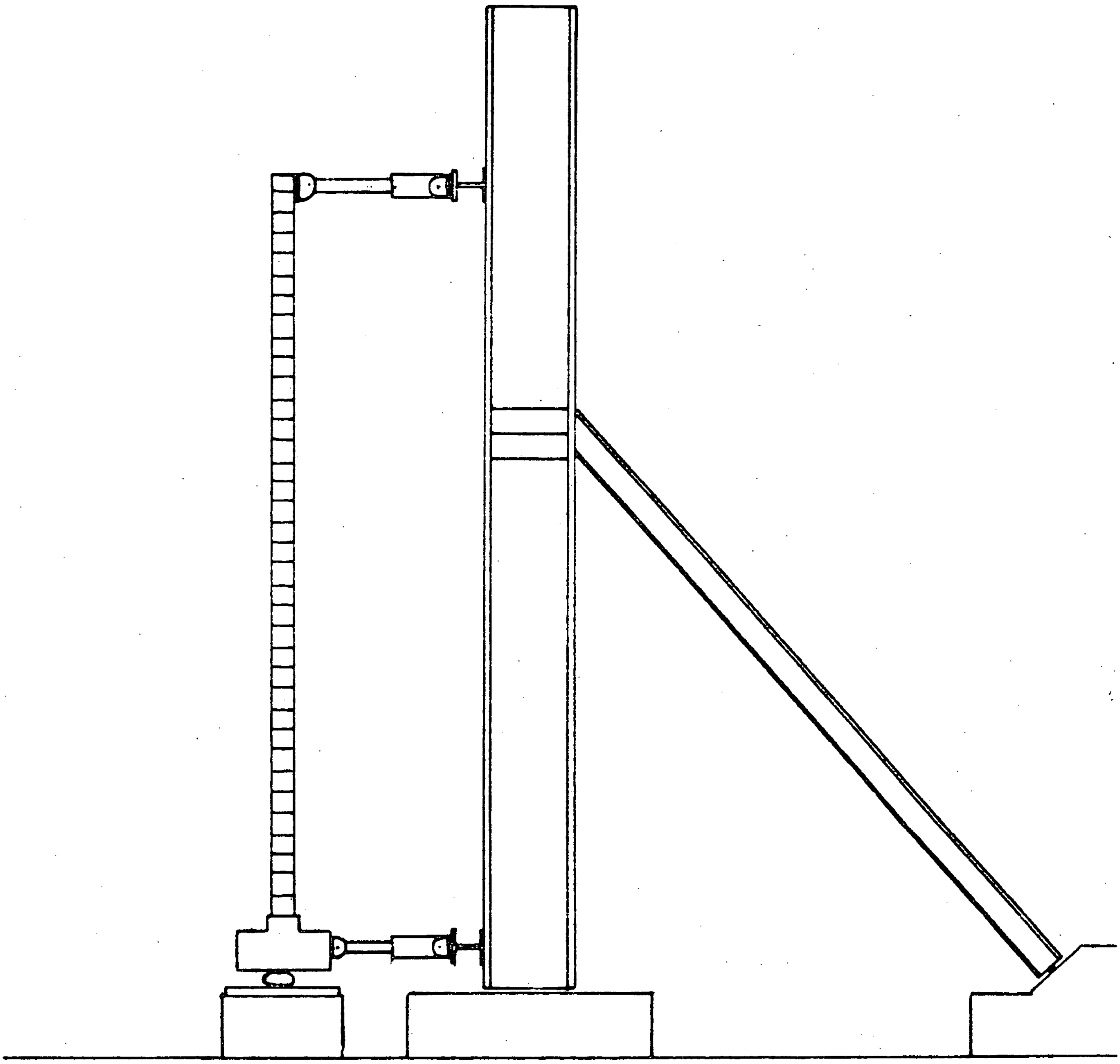


Figure 2 Test assembly

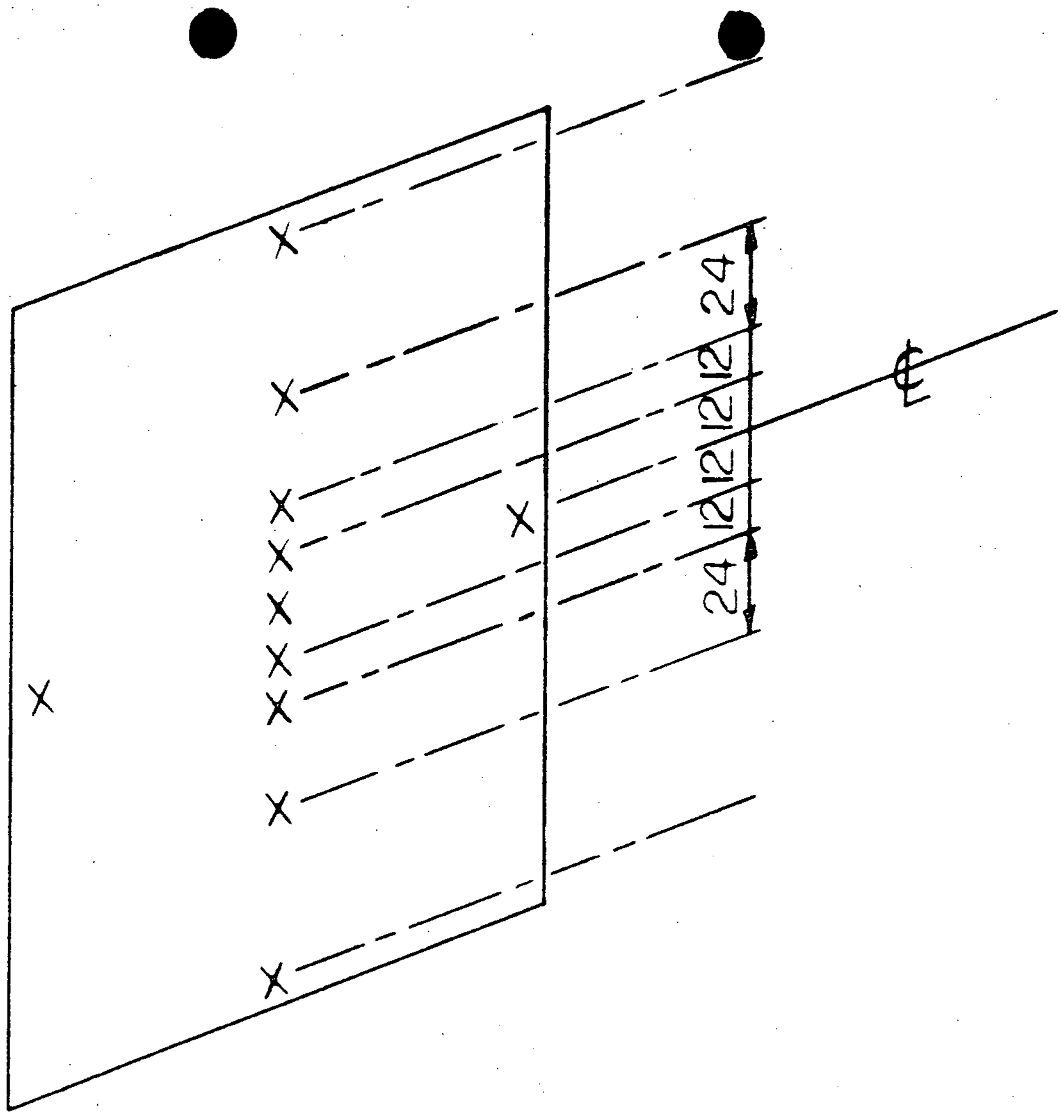


FIGURE 3 – LOCATION OF POTENTIOMETERS

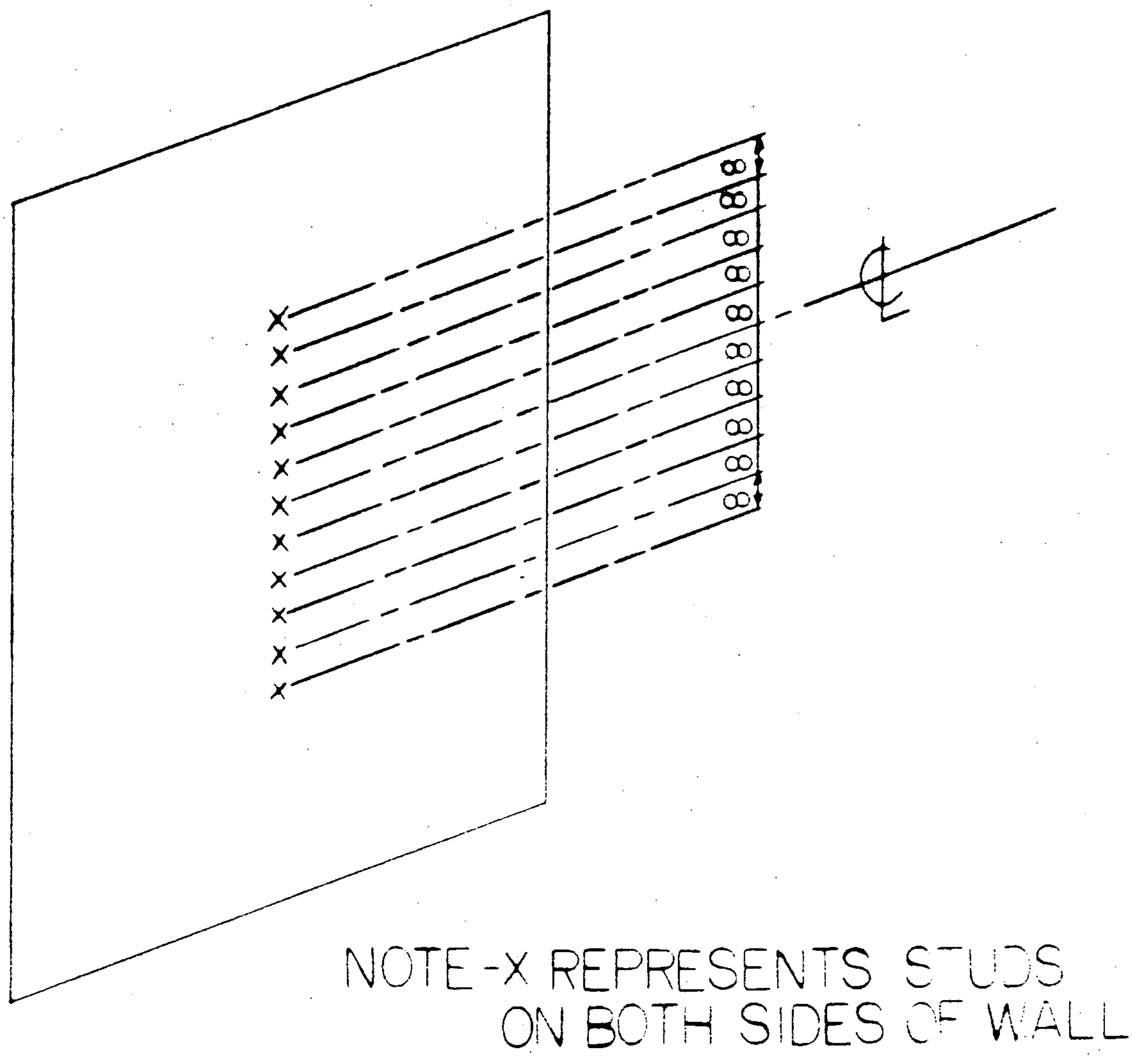


FIGURE 4 - LOCATION OF STUDS FOR CURVATURE MEASUREMENT

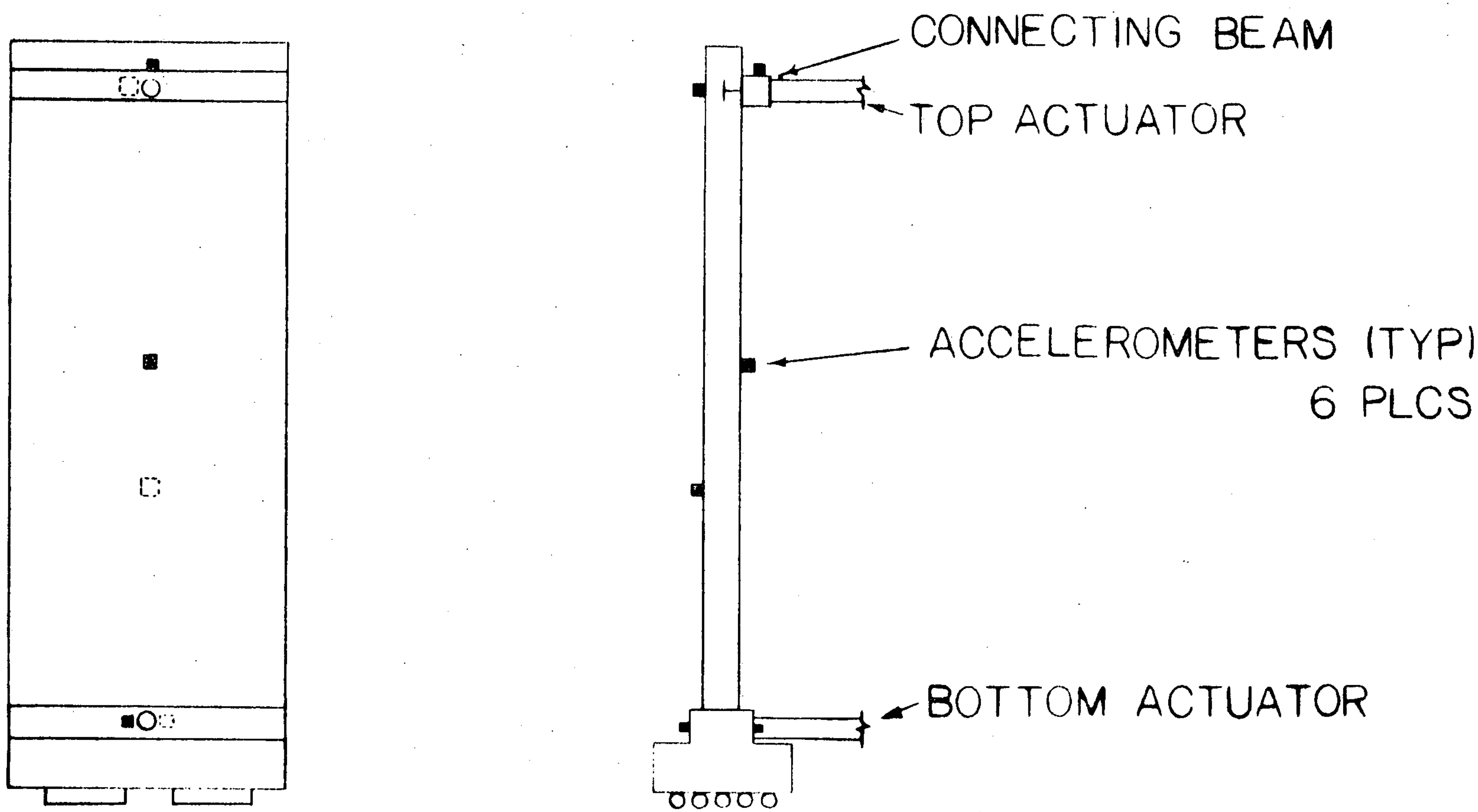
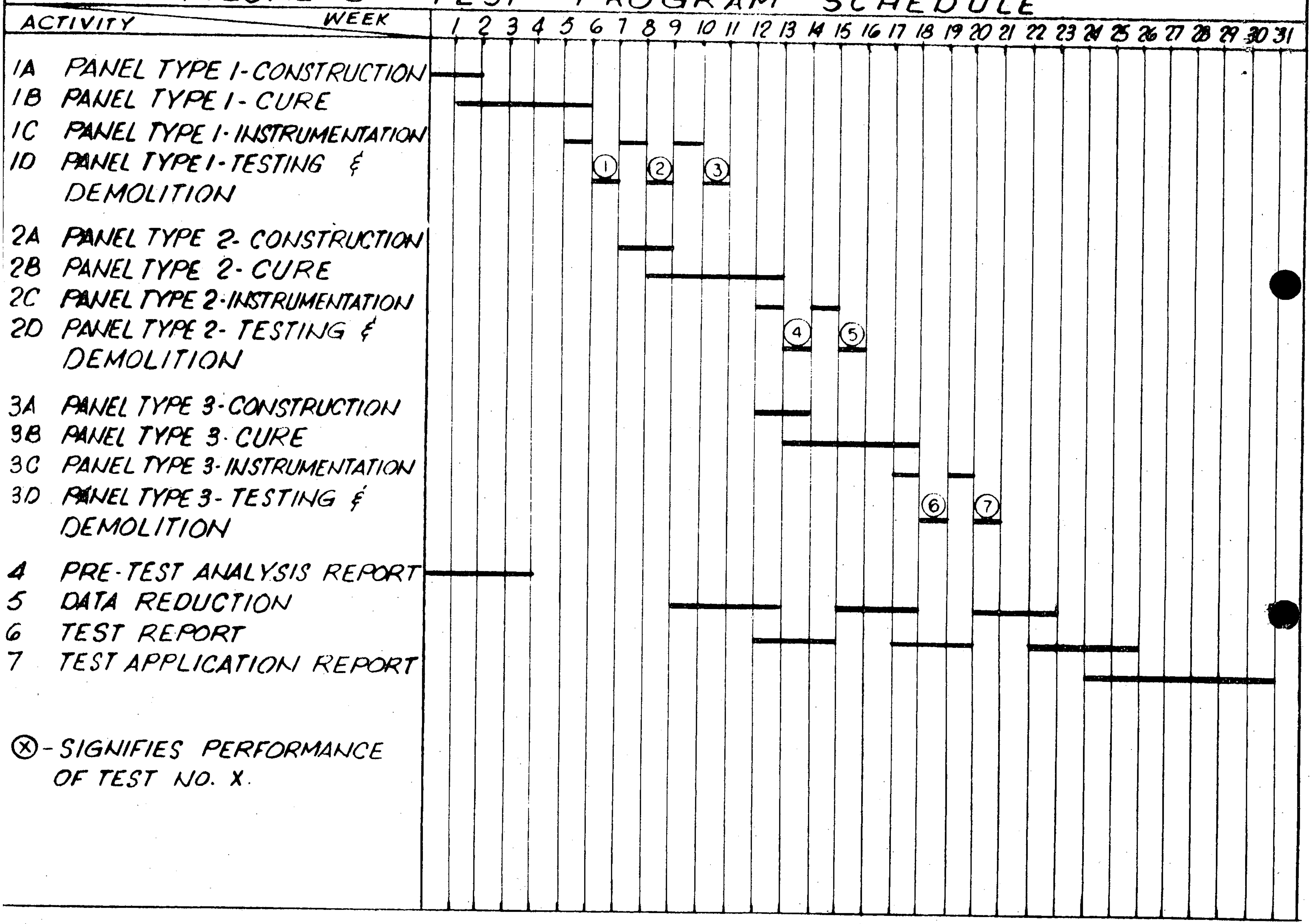


FIGURE 5 – LOCATION OF ACCELEROMETERS

FIGURE 6 - TEST PROGRAM SCHEDULE



ⓧ - SIGNIFIES PERFORMANCE OF TEST NO. X.