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3D BEHAVIOR OF SHOTCRETED LIGHT WEIGHT PANEL BUILDINGS

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SUMMARY

Specially fabricated two layers of reinforcement grids which are in contact by zig zag shape continuous cross bars, are used to construct first the skeletal part of a 3D structure. Since a layer of foam sheet has been placed in between the two surfaces of reinforcement cages there is practically no difficulty for shotcrete application from each side during the construction phase. 1/2 scale model of one story specimen has been prepared in the laboratory using this material and construction technique and tested for lateral loads. The light weight panels cut the total weight of the structure roughly in half. And the monotonic lateral loading indicates that ultimate load reached may be 10 times higher than the design load and all relative displacement requirements are perfectly satisfied. The 2D test results of panels made of similar material have been summarised first and then used in theoretical work presented here in.

INTRODUCTION

Specially prepared two layer wire cage with a foam layer in between have been used to strengthen the damaged RC frames, see Fig 1a, or used to build low rise structures, see photographs 1-5. The lateral and vertical cross sections of the special material used is given in Figure 2b. After having installed, the two surfaces of diaphragms are shotcreted, (see Photograph 5). Several techniques, to connect the damaged frame to the diaphragm have been employed and tested. The envelopes of the hysteresis curves achieved at the end of these two cyclic loading are presented all together in Fig 1b. The details of this investigation can be found elsewhere [2]. Curve **E** in Fig 1b belongs to the reinforced concrete frame subjected to the same displacement pattern prior to the installation of diaphragms. Curve **B** which has been obtained analytically subtracting the curve **E** from curve **A** which corresponds to the panels with the same detailing features of the panels used in construction of 3D specimen investigated in this paper. Curve **B** is given independently in Fig 1c from which the relationship between shear stresses and shear distortions is approximately derived and presented separately in Fig 1d. The way followed up in this derivation has been summarised in the same figure by means of two equations. Declined part of that curve has not been referred later on in the theoretical calculation, but the lateral line has been utilised instead.

The efficiency of added diaphragms on the lateral stiffness and strength of the damaged frame can easily be observed by the comparison of the slopes at the beginning and the ultimate points they reached. In Fig 1a one can hardly see the fine cracks at ultimate load level on the surface and the limited amount of damage at the diaphragm corners.

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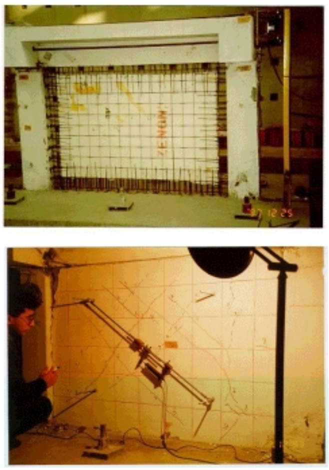
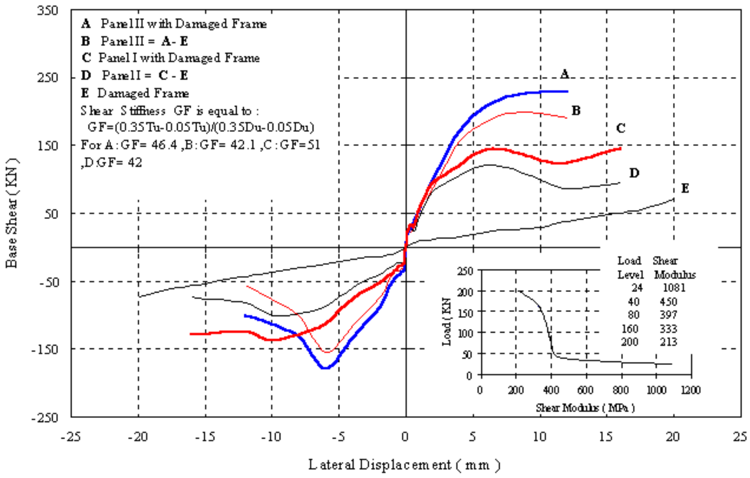
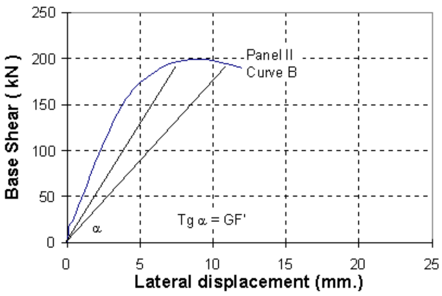
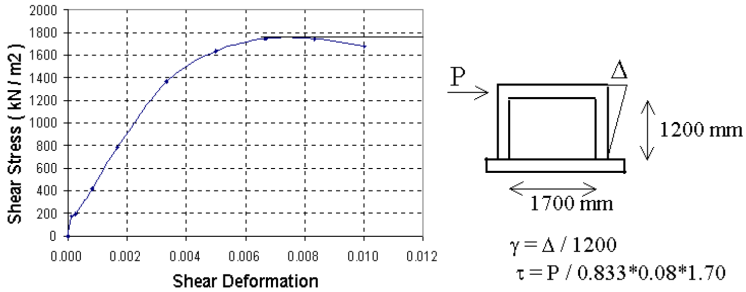




(a) **Fabrication of Specimen and Tested Panel** (b) **Load Displacement Envelope Curves**





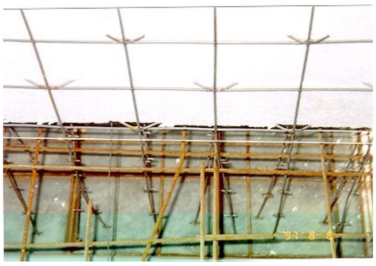
(c) Load-Displacement Curve B **(d) Shear Stress - Strain Relationship**

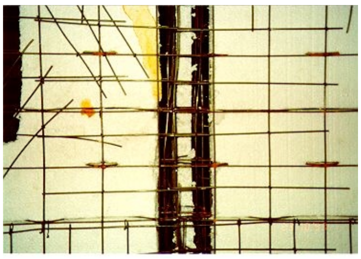
Fıgure 1. 2D Test Results of the Shotcreted Lightweight Panel

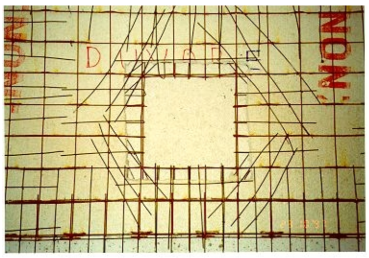
SPECIMEN

A three dimensional specimen with 1/2 scale has been constructed in the laboratory using the special light weight panel reinforcement cages which are converted to structural walls later by means of shotcreting in situ. General layout, cross sections, and the details of the special shotcreted panels are schematically all given in Fig 2.

The anchorage of the specimen down to the mat foundation which has been tied to the testing floor by post tensioned high strength bolts panel connections, measures taken around the wall openings and several stages of the fabrication of the specimen can be followed up in the set of Photographs 1- 5. The specimen is exactly a scaled down replica of a real structure, which is under investigation. Very good heat insulation, reduced total weight and very high construction speed are challenging basic features of this simple construction technique.

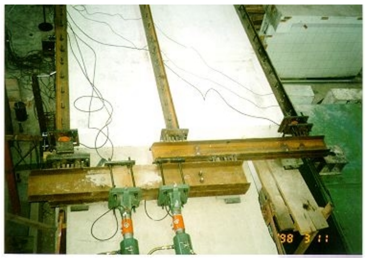






1. Wall and Foundation Anchorage **2.Connection of Three Walls** **3.Detailing Near Opening**

Some other preliminary tests using the same kind of panels have been carried out in the laboratory before the three dimensional specimen has been prepared. Uniaxial loading tests of the panels [1] , inplane cyclic loading of panels [2] and out of plane loading of panels [3] are among them. Depending on these early findings it is expected to have more ductile behaviour, higher energy absorption capacity , higher safety margins and reparable local failures rather than overall failures .



4.Specimen During Construction **5.Shotcreting** **6.Specimen During Testing**

The specimen has been designed for 26 kN base shear force which corresponds to 25% of total weight of the structure and satisfies the requirements of new Turkish Earthquake Code of 1998 [4]. Bar diameters used in the wire mesh is 3 mm. They are undeformed and automatically welded to each other at each 10 cm both in lateral

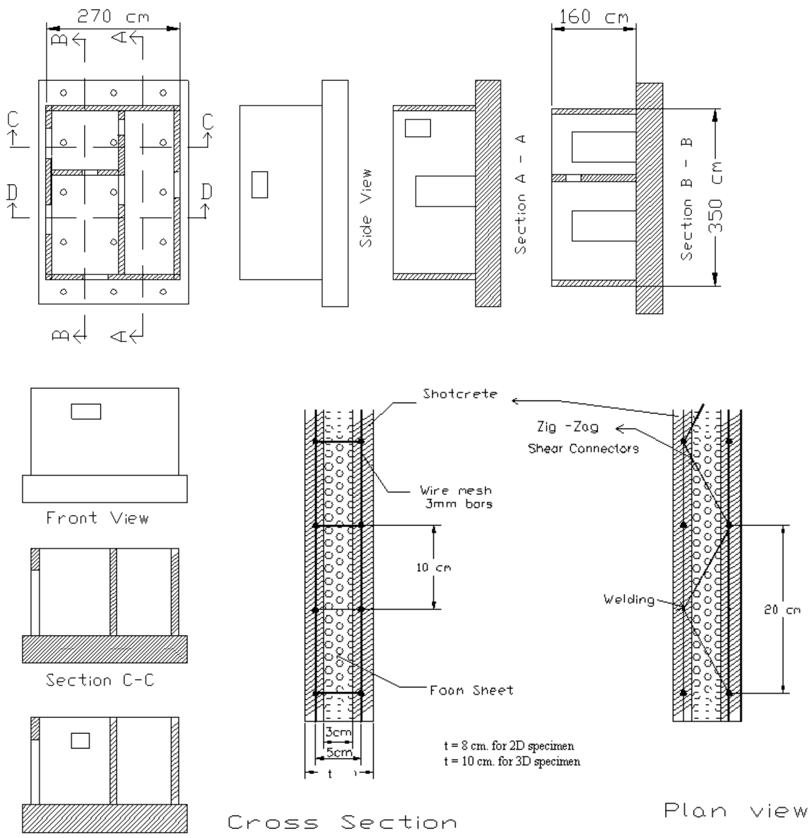


Fig 2. Plan , Cross Sections , and Details of Special Shotcreted Panels

and vertical directions the yield strength of these bars is around 500 MPa. Cylinder tests indicate that the shotcrete has the average compressive strength of 14 MPa. It has been indicated that cylinder tests are good enough to show the shotcrete quality [5].

TESTING SETUP AND TESTS

Two double acting oil jacks with 300 kN capacity have been placed in horizontal position between the specimen and the reinforced concrete reaction wall. And the lateral load obtained by jacks is divided to two equal parts first. And one of the loads is divided again to two, as it can be seen in Fig 3 and Photograph 6 so that the loads transferred to each wall will be proportional to their initial lateral rigidities. Then each of these lateral loads are distributed along the shear walls by means of the shear studs embedded into the specimen and rigid loading arms which are placed on top of them. Doing that lateral concentrated loads coming to each wall are transformed more or less to uniformly distributed load on the wall. The loads transferred to the walls 1 and 3 are recorded simultaneously through the load cells shown in Figure 3. Therefore the loads which goes to middle wall, W2, can be computed simply subtracting the loads taken by W1 & W3 from the total load applied to the specimen synchronously by two jacks.

All in all it can be said that the lateral load distribution has been kept almost equivalent to the distribution of actual inertia forces expected in an earthquake. Since structure is relatively rigid structure and elastic behaviour is expected till to the level of design load this assumption is valid at least up to that level. It is assumed that the walls perpendicular to W1,2 & 3 are not carrying shear loads.

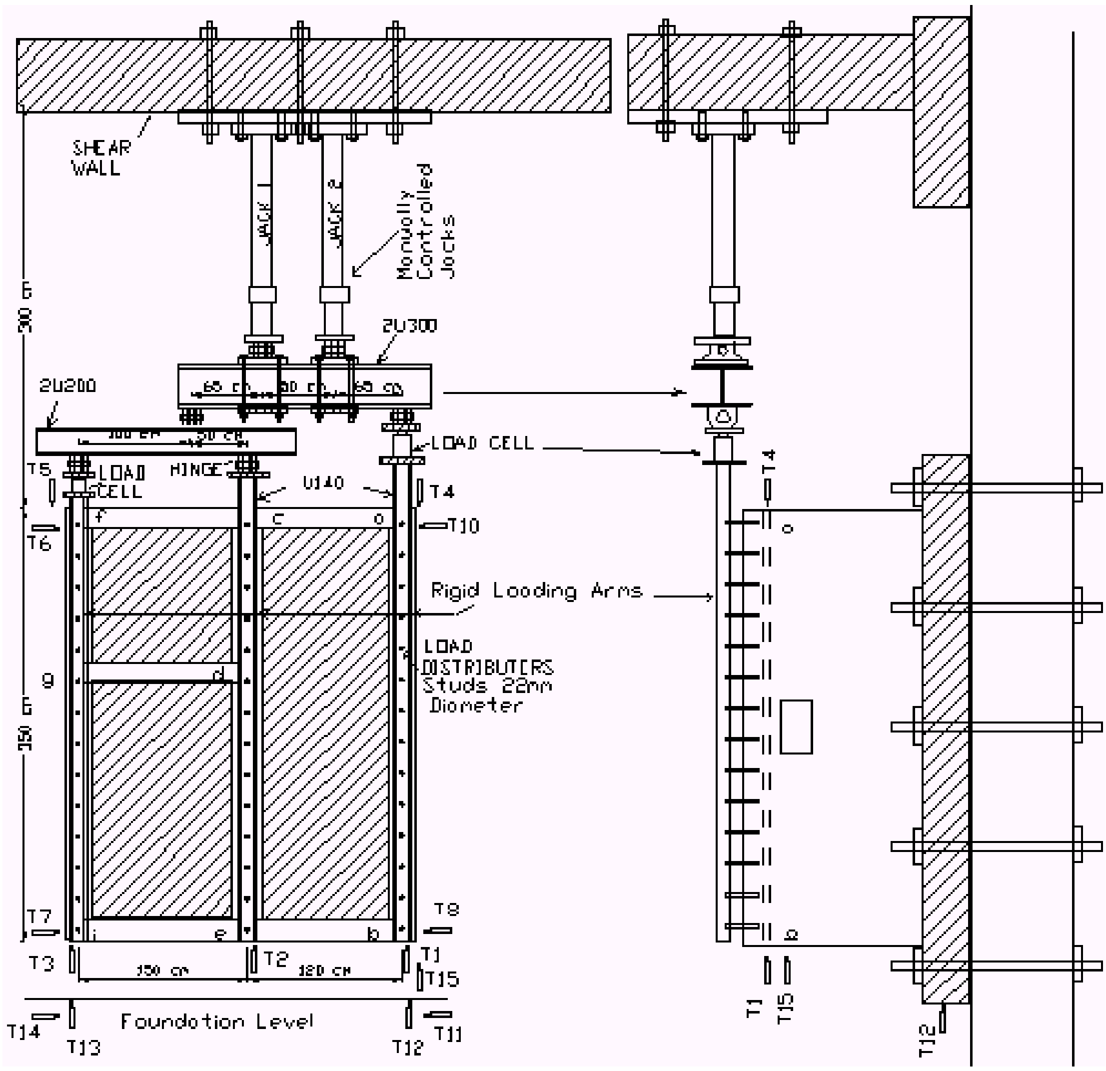


Fig 3.Load Distribution and Test Setup

Inplane and out of plane displacements from each end of the specimen, and the possible relative slippage on the loading floor are all automatically recorded , and the proceeding displacement curves have been achieved , see Fig 4 , and Fig 5a,b respectively. The average of the records of transducers T1, T2 & T3 and total lateral load have been utilised for drawing Fig 4. It has been observed that the slippage on the floor and out of plane displacements are negligible. Although the lateral load level achieved during testing is roughly 10 times bigger than the design load level, the ultimate load capacity of the structure has not been reached due to the deficiency in loading apparatus.

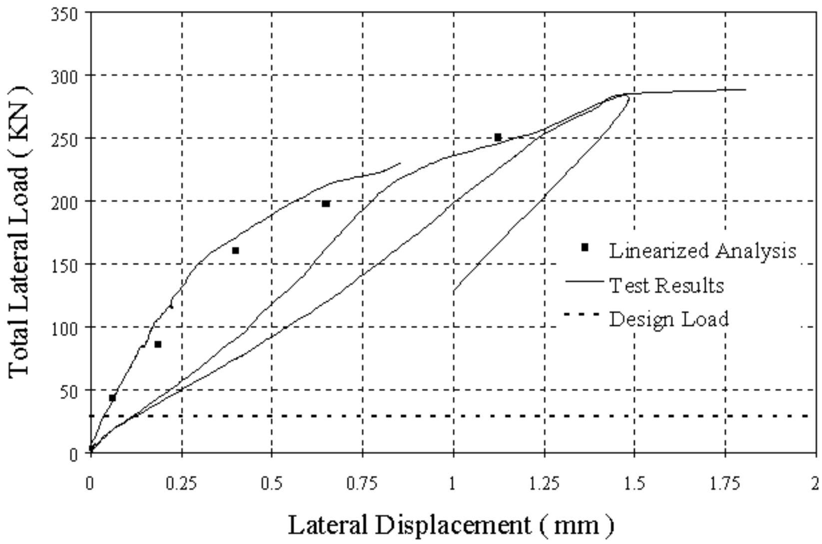


Fig 4. Lateral Load Floor Top Displacement Curve

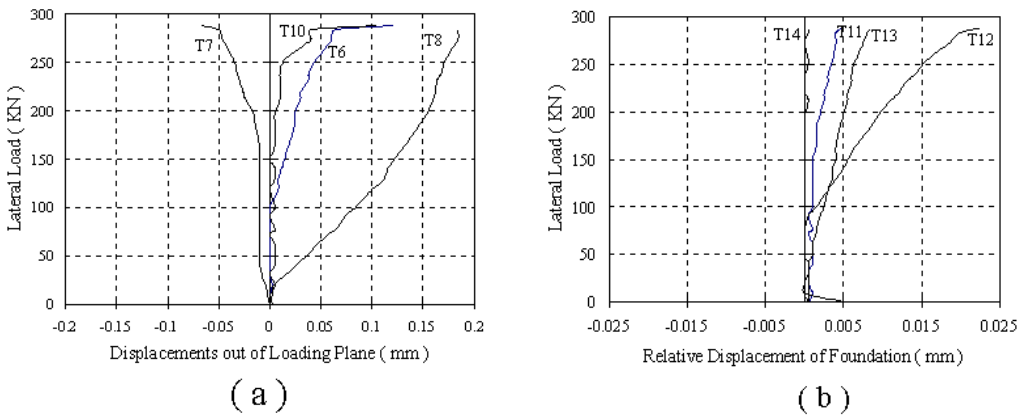
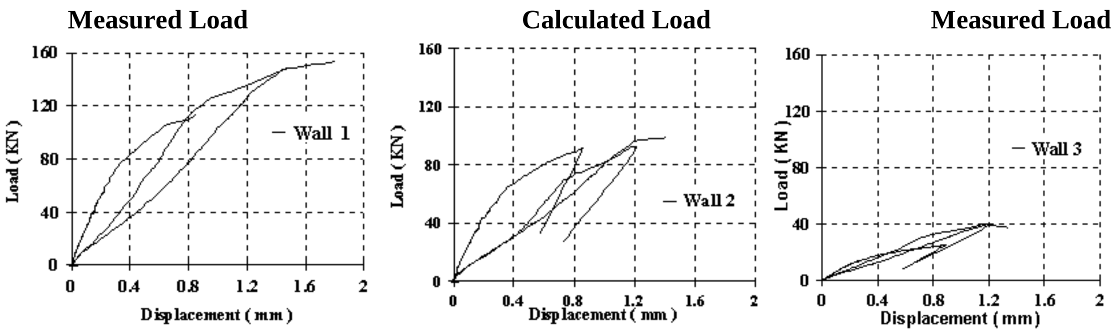


Fig. 5 (a) Displacements Perpendicular to Loading Direction, (b) Foundation Slippage

Load deflection curves obtained from individual walls are presented in Fig 6a, and the crack patterns at each surface of the walls are given in Fig 6b. It should be noted that, even at the maximum load level, only miner very fine distributed cracks have been observed. No local failure detected.



(a)

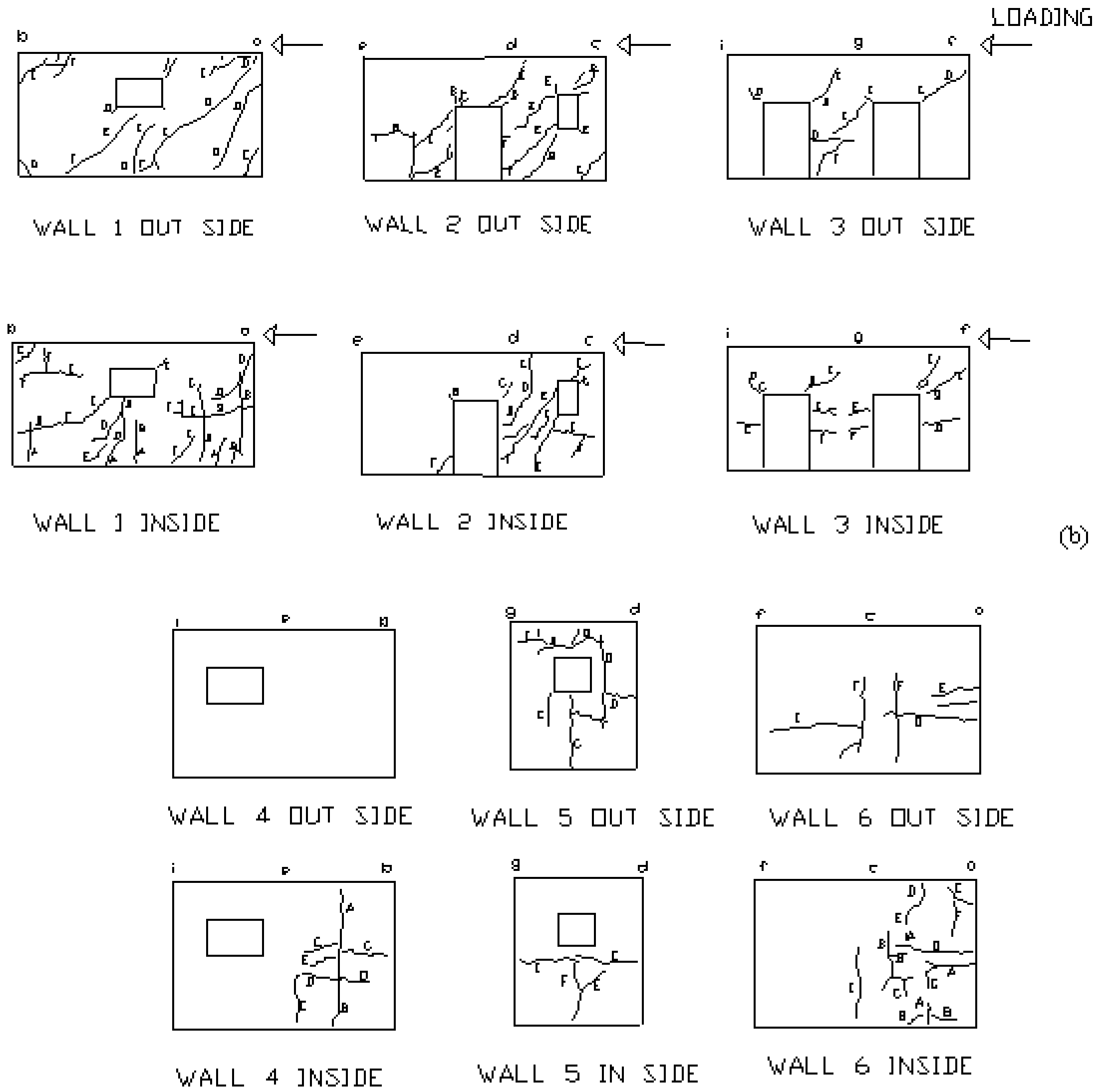


Fig 6. Cracks Pattern of Walls in the Loading Direction

THEORETICAL WORK

Finite element model of 3D specimen is given schematically in Figure 7. Membrane elements have been employed to represent the walls and the roof which is supported by all the walls. It has been assumed that roof is infinitely rigid in its own plane and its dead weight is negligible.

The general purpose computer program SAP90 [6] has been utilised to analyse the structure. In order to introduce the material nonlinearity into that program, modulus of elasticity of the elements at each wall have been altered according to the total shear force of the wall at that particular load level using the experimentally found equivalent shear modulus and taking the puassion ratio as 0.20. So the square shape spots, which are the part of theoretical load-deflection curve, are reached, (see Figure 4).

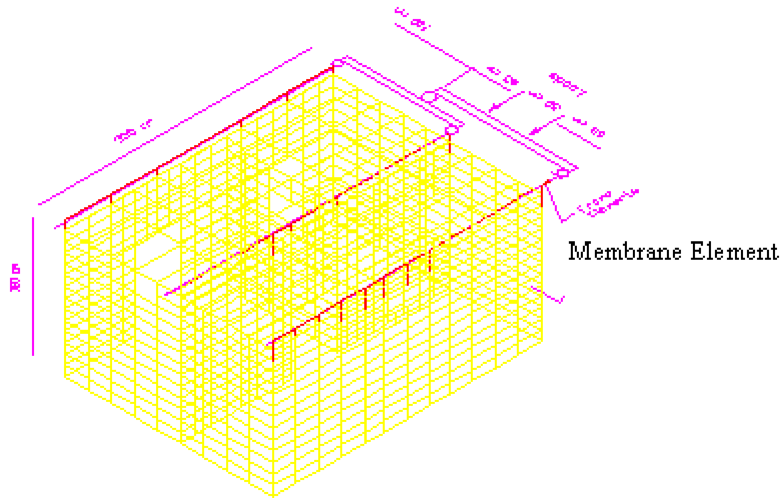


Fig 7. Finite Element Mesh Used in the Linearized Analysis

CONCLUSION

The ½ scale specimen which has been tested for monotonic lateral loads in the laboratory consists of very well connected panel elements shotcreted in-situ. Although the lateral loads were increased to roughly ten times higher load levels then the design loads, only minor fine cracks have been observed on the surfaces. No important local failures have been detected. It was also interesting to observe that no separation have been occurred between two layers of each walls.

Even by the simplified procedure proposed in this paper the experimentally found nonlinear behaviour of the structure has been obtained theoretically as well.

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