A PROPOSED DESIGN FOR R.C BLAST RESISTANT BARRIERS

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ABSTRACT

In this study a proposed design for reinforced concrete barriers in industrial units is presented. The barriers are deemed to mitigate the hazards of internal explosions to protect the surroundings.
The Technical Manual (TM5-1300) for fortified structures recommends the use of lacing reinforcement barrier walls when the plastic rotation exceeds a specified limit. Such reinforcement is essential in shear design but it needs special skill and additional cost. To avoid using lacing reinforcement, walls of grillage system is proposed in this study to reduce the plastic rotation of panels. The panels are designed to respond plastically, while the grillage members respond elastically. This is advantageous from recruiting point of view since only the blast-damaged panels may be repaired.
Results have shown that the (SDOF) analysis method as recommended by the (TM5-1300) [D.C., 1992] gives an upper bound solution as compared with the (F.E) method. Cubicles of ribbed walls show higher blast resistance and exhibits smaller plastic support rotation of panels than that of flat-sided walls. The minimum thickness required to avoid using lacing reinforcement have been obtained for different cases of grillage arrangements and charge weights.

الخلاصة

في هذا البحث تم اقتراح تصميم لجدران خرسانية مسلحة لاستخدامها داخل المعامل لغرض الحماية من خطر الانفجارات الداخلية المحتملة، ولغرض تماشي استخدام التسليح المتعرج تم اقتراح نظام شبكي لتقليل الدوران اللـدن عند المساند وتصميم اجزاء الجدار بين اعضاء الشبكة بشكل لدن وباقي الاعضاء بشكل مرن. وهذا من شانه ان يسهل الصيانة عند تعرض المنظومة للانفجار. اذ ان اعضاء الشبكة الرئيسية ستبقى ضمن حدود المرونة.

اضهرت النتائج ان طريقة التحليل الديناميكي احادي الحركة تعطي نتائج اعلى من طريقة العناصر المحددة. وتم ايجاد اقل سمك للجدران يسمح بعدم استخدام التسليح المتعرج ولحالات مختلفة لشدة الانفجار

KEY WORDS
Blast loads. concrete Barriers, Chemical Plants.

INTRODUCTION

Some structures like shelters and chemical plants need to be designed to resist dynamic, as well as static loads. Safety provision may necessitate the use of blast-resistant cubical structures in such units. These structures are intended to mitigate the risk of accidental explosions in the surrounding working area. A major objective of this research is to propose a practical design for reinforced concrete cubicles to resist internal explosions without using lacing reinforcement, **Fig. (2a)**.Shear strength requirement of such cubicles needs the use of lacing reinforcement when the plastic rotation of panels exceeds 2° at supports [(TM5-1300)[D.C., 1992]]. In order to reduce this rotation it is proposed in the present research to investigate the possibility of using cubicles of ribbed walls and to compare the dynamic behavior with that of flat sided walls. Hence it is the intention of the present paper to deal with the dynamic analysis of plates and grillage systems.

BLAST IMPULSE

In the present study the method of the calculation of the average blast impulse on the cubicle wall was that outlined in ((TM5-1300) [D.C., 1992]). A computer program has been coded for this purpose to deal with the proper charts of .((TM5-1300) [D.C., 1992]) to determine the value of impulse(t_0) for any cubicle wall, charge weight and its location for the range of values of the parameters.

The blast duration t_o may be estimated by the following formula [1,2,3,4]: -

$$t = (t_A)_F - (t_A)_A + 1.5(t_b)_F \quad .(1)$$

Where:-

$(t_A)_F$ = Time of arrival of the blast wave at the point on the element furthest from the explosion.

$(t_A)_A$ = Time of arrival of the blast wave at the point on the element nearest to the explosion.

$(t_b)_F$ = Duration of the blast pressure at the point on the element furthest from the explosion.

The actual pressure-time relationship may be approximated by a peaked triangular pulse when the blast duration is long in compassion with the response time of the element. The peak pressure (P_r) is calculated from the following formula: -

$$P_r = \frac{2i_b}{t_0} \quad .(2)$$

Table (1) summarizes the results of blast pressure time functions for different charge weights exploding at cubicle center. The general layout of the cubicle considered in this paper is shown in Fig.(1).

RESISTANCE – DEFLECTION RELATIONSHIP

For the purpose of elasto-plastic analysis, the resistance- deflection relationship is essential. In the present research, the resistance - deflection behavior for each wall was determined by utilizing the finite-element analysis. Quadratic lagrangian 9-node parametric thick plate elements have been used (Mindlin Plate). The computer program of Reddy, [1984] for the linear analysis of thick plates has been modified in the present study assuming linear-elastic behaviors between any two successive stages of yield lines development. Average plate rigidity for cracked and gross sections was adopted. This has been based on reported experimental evidences [Hinton, 1988].

Table (2) summarizes the results of the piece-wise linear resistance-deflection model for the wall of the cubicle shown in **Fig. (1)** which is assumed fixed at three edges and free at the roof level. An equivalent bilinear resistance-deflection model can be determined from the piece-wise linear resistance-deflection model by equating the strain energy of the two relationships **Fig.(2b)**. The equivalent maximum elastic deflection (Y_E) for the three-step system is expressed by the equation: -

$$y_E = y_e\left(\frac{r_{ep}}{r_u}\right) + y_{ep}\left(1-\frac{r_e}{r_u}\right) + y_e\left(1-\frac{r_{ep}}{r_u}\right), \quad (3)$$

Where y_e, y_u, y_{ep}, r_{ep}, r_e, r_u, are as defined in **Fig. (2b)**. For the ribbed walls design, each wall panel is assumed fixed all around. The results for the resistance- deflection relationships are given in **Table (3)**.

DYNAMIC ANALYSIS

For blast-resistant structures, an amount of plastic deformations consistent with a reasonable factor of safety against important damage may be permitted. Cubicles of either flat sided walls or ribbed walls are considered. Different rib arrangements were considered to study the effect on the plastic support rotations of panels. For panels exhibiting plastic support rotation of less than (2) degrees, lacing reinforcement will no longer be required [(TM5-1300) [D.C., 1992]]. Hence a considerable economy could be achieved, **Fig (2a)**.

In the present study the panels of the ribbed walls to be designed to exhibit plastic dynamic response, while the ribs are to be maintained within the elastic limit. This is advantageous from the reconstruction point of view since only damaged panels are required to be repaired after accidental explosion. Two methods are used to estimate the nonlinear response of the panels, the single degree of freedom (SDOF) method that had been recommended by (TM5-1300) and the finite element method.

SDOF Method

In this method each wall of the flat sided cubicle is replaced by a single equivalent mass and a single equivalent spring. The (SDOF) method is still considered to be the major practical method, because it permits rapid analysis of even complex structures with a reasonable accuracy in most cases [Delroy, 1999, Li, Q. M., 2002Marceio, 2002, D.C., 1986]. By equating the kinetic energy for the real and equivalent systems, the equivalent mass can be determined. Also by equating the work done by the dynamic forces for the real and equivalent system spring stiffness can be determined. This is applied for the elastic, the equivalent elastic- plastic and plastic ranges. Results of (SDOF) equivalent parameters are tabulated in TM5 – 1300, [D.C., 1992]] for the elastic, elastic – plastic and plastic ranges and this method had been recommended by the TM5 based on previous experimental evidences. The same procedure is applied for the panels of the ribbed walls.

(F.E) Method

In the present study, a computer program coded in Fortran77 [Reddy., J. N., 1984] is used in carrying out a linear dynamic analysis of the flat walls and panels of ribbed walls. The 9-node quadratic quadrilateral isoperimetric plate element is used. Consistent mass approach has been adopted and Newark- ß integration scheme was followed. From the (F.E.) linear dynamic analysis the maximum dynamic deflection of the wall or the wall panel has been obtained (y_{me}). If this deflection is traced over the equivalent bilinear resistance- deflection relationship and by requiting the strain energies (areas ACD and ABEF) **Fig. (3)**, the plastic maximum deflection y_{mp} can be evaluated [Baker, W.E., 1986].

Grillage Analysis

The usual grillage analogy method is suitable for the analysis of plate - ribs construction in which the load distribution takes place mainly through flexure and torsion in the longitudinal and transverse directions. For the cases of plate-ribs construction, the system may be idealized as an equivalent grillage members connected together at discrete nodes. The properties of longitudinal or transverse members are given the properties of the corresponding ribs plus the associated portions of the slab. The grillage members was analyzed and designed to remain within the elastic limit.

A computer program coded in Fortran77 is considered in carrying out a linear dynamic grillage analysis of grid systems of **Fig. (4).**

APPLICATIONS

The general layout of the cubicle considered in this study is shown in **Fig.(1).** A cubicle with frangible roof was considered to minimize the amplification of blast pressure within a structure. The mass of (TNT) charge considered are (25,30,35,40,45,50,55,60,65,75 and 80 kg) and located at the center of the cubicle [Raad, K. SH., 1994].

According to the American Technical Manual (TM5-1300) of the U.S army, each wall (or panel) is assumed to have fixed type boundary conditions at the monolithic joint with the other walls. The dynamic analysis was made for cubicles of flat sided walls and also for cubicles of ribbed walls. For all cases constant cubicle thickness is considered.

The cubicle shown in **Fig. (1)** is of dimensions (8m*8m*8m) which will be studied for the following cases:-

Cubicle of Flat Sided Walls

The cubicle shown in **Fig. (1)** is analyzed for different thickness (200,250, … and 600mm). The proposed nonlinear dynamic analysis presented in sec. (4.1) has been used for the panels of each thickness and for different charge weights. The results of plastic rotations of the panels are given in **Fig. (5).**

Cubicle of Ribbed Walls

The cubicles of ribbed walls are analyzed for (300 mm) thick panels. This thickness is selected from the practical point of view to provide a protection against a probable indirect hit of a (250 kg) G.P.bombs.[D.C., 1992].

To reduce support rotations of panels, attempt is made in this study to use cubicle of ribbed walls and hence to avoid using lacing reinforcement.

Cubicle Type I

This type represents a cubicle of ribbed walls without edge rib at its top (roof level). Four cases of cubicles are considered based on the number and arrangements of the ribs.

The (SDOF) and the finite element methods of nonlinear dynamic analysis have been used for the panels of each case and for different (TNT) explosions.

Figs. (7,8,11,12) show the results of the plastic rotation and the ductility ratio (which is the ratio of the ultimate plastic deformation y_{mp} to the yield deformation y_E ,**Fig.(3).**) for the cubicle cases(1,2,3,4). **Fig.(4).**

As mentioned earlier, it is intended in the present study to design the ribs to remain within elastic limit. A linear grillage dynamic analysis of the ribs was carried out. The idealized load-time history acting on the ribs **Table (4)** is an initially peaked triangle defined by a peak load, which is the maximum dynamic reaction transferred from panels to ribs corresponding to the ultimate support shear of the panels in the vertical and horizontal directions. The duration of this load corresponds to that of maximum support rotations of panels. To maintain the ribs within the elastic limit during explosion, a number of trial analyses have been carried out to achieve an adequate rib dimensions which are given in **Fig.(4).**

Cubicle Type II

This type represents a cubicle of ribbed walls having edge ribs at roof level around the cubicle. The methods of nonlinear dynamic analysis of panels used in cubicle type I are applied for the present type for different (TNT) explosions. **Figs. (9,10,13,14).**
Typical acceleration-time histories for different nodes and ribbed cubical cases are shown in **Figs. (15,16,17,18).**

DISCUSSION OF RESULTS

The results indicate that the (SDOF) method gives the upper bound solution for plastic rotations of panels as compared to the finite element method. **Fig. (5)** shows that increasing the thickness of the flat walls will reduce the plastic rotation significantly. The results in **Figs. (7-14)** show that the maximum support rotation of panels (which is one of the most important criteria to decide whether lacing reinforcement is required or not) is affected evidently by the rib arrangements.
It is seen from **Fig. (7-14)** that the cubicle type II is stiffer than the cubicle type I and it can be used to carry a higher blast pressure. **Figs. (15-18)** show that the grid system of cubicle (Type II-case 4) exhibits lower acceleration among the other cases. So, cubicle type II is preferable and to be recommended in such type of construction.
Fig. (6) gives the limit for the wall or panel thickness for which no lacing reinforcement is required, For instance if the charge weight – volume ratio is (0.08 Kg / m^3) the limit thicknesses are 450mm and 200mm for the flat sided wall and for the ribbed wall respectively. For a ratio of (0.15 Kg/m^3) these limit thicknesses become 570 mm and 400 mm respectively.

CONCLUSIONS

In concise statement and in view of the findings of the present paper, the following conclusions can be drawn: -

1- The present study suggests a practical design for reinforced concrete cubicles to resist internal explosions. The proposed ribbed walls are intended to reduce the plastic rotations of panels to be less than 2 degrees. Hence no need to use lacing reinforcement for shear design.
2- The proposed ribbed walls are to be designed so that panels repairing are possible after accidental explosions. This means that the panels can be repaired without the need for demolishing the whole cubicle and then reconstructing it again. This is attributed to the fact that the ribs are to be designed to remain within the elastic limit.
3- The minimum thickness required without using lacing reinforcement for wall panels has been obtained for cubicles of flat or ribbed walls and for different charge weights.

Table (1) Pressure- Time History for walls Exposed to Different Charge Weights.

Charge Weight (kg)TNT	Peak Pressure (kN/m^2)	Duration of Pressure (msec)
25	296	13.350
30	390	12.720
35	510	12.040
40	588	11.697
45	678	11.355
50	814	10.520
55	898	10.320
60	974	10.280
65	1064	10.074
70	1160	9.817
75	1256	9.578
80	1339	9.442

Table (2) Resistance – Deflection Characteristics for Cubicle of Flat Sided Walls.

t (mm)	re (kN/m^2)	ye (mm)	rep (kN/m^2)	Yep (mm)	ru (kN/m^2)	yp (mm)	YE (mm)	KE (kN/m^3)
200	13.714	17.429	17.898	36.465	26.385	70.119	51.883	509
250	17.910	11.761	22.183	22.269	35.347	49.184	36.654	964
300	22.107	8.449	27.604	16.315	44.058	35.947	26.848	1641
350	26.413	6.518	33.088	12.685	52.930	27.962	21.288	2486
400	30.499	5.084	38.443	10.042	60.641	21.482	16.074	3772
450	34.696	4.145	43.981	8.185	67.470	16.890	12.558	5373
500	43.138	3.672	54.663	7.346	84.486	15.269	11.360	7437
550	53.625	3.412	70.965	7.249	105.623	13.640	10.334	10221
600	62.727	3.065	79.821	6.193	122.218	12.656	9.407	12993

Table (3) Resistance – Deflection Characteristics for panels of Ribbed Walls.

Cubical type		re (kN/m^2)	ye (mm)	rep (kN/m^2)	Yep (mm)	ru (kN/m^2)	yp (mm)	YE (mm)	KE (kN/m^3)
Type (I)	1	83.515	2.052	106.717	3.914	176.240	12.240	10.223	25719
	2	96.614	1.824	112.463	3.810	221.201	9.155	8.787	25112
	3	187.908	0.748	242.934	7.084	334.531	7.766	5.774	57933
	4	187.860	1.034	236.985	5.397	396.400	8.919	6.989	56717
Type (II)	1	135.764	1.265	210.980	3.471	279.227	10.750	5.431	51408
	2	208.959	0.693	309.943	1.150	451.943	16.777	6.625	68217
	3	224.368	0.702	322.459	1.705	456.481	15.998	6.060	75324
	4	305.394	0.562	474.588	1.525	628.241	4.780	2.378	264189

Table (4) Applied Load –Time History for Grillage Systems.

Load-Time History	Cubicle Type I*				Cubicle Type II **			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Load (Pm) (kN)	4809	4833	4217	5351	5350	5696	5616	5351
Time (tm) (ms)	23.357	22.725	15.037	14.533	17.562	12.185	12.240	7.106

* Cubicles with edge beams at roof level.

** Cubicles without edge beams at roof level.

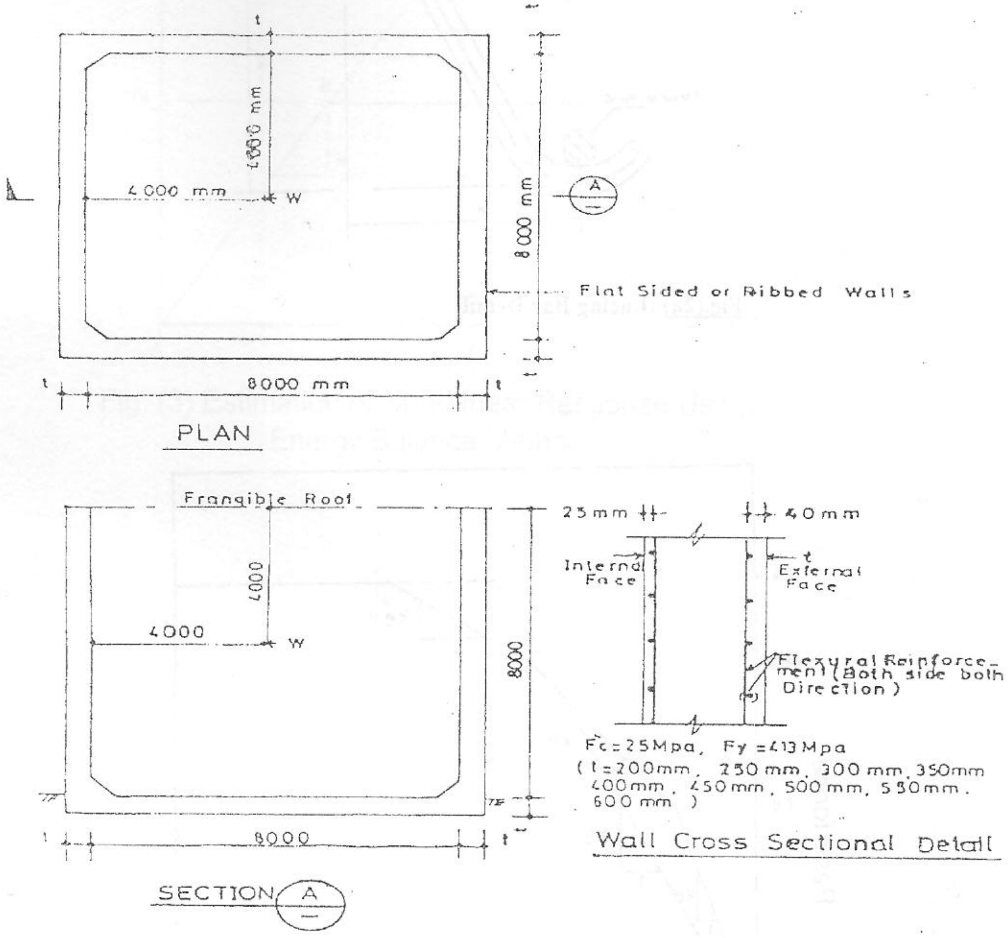

Fig.(1): Plan, Section and Cross Sectional Detail for the Cubical Barrier Used in the Present Study.

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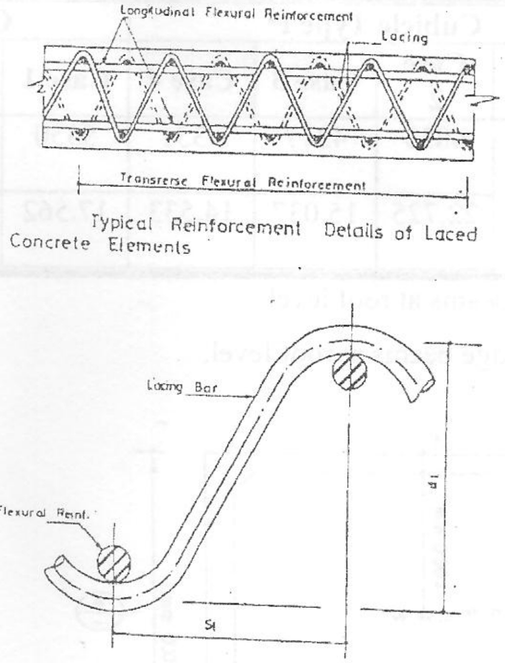

Fig.(2a) :Lacing Bar Detail.

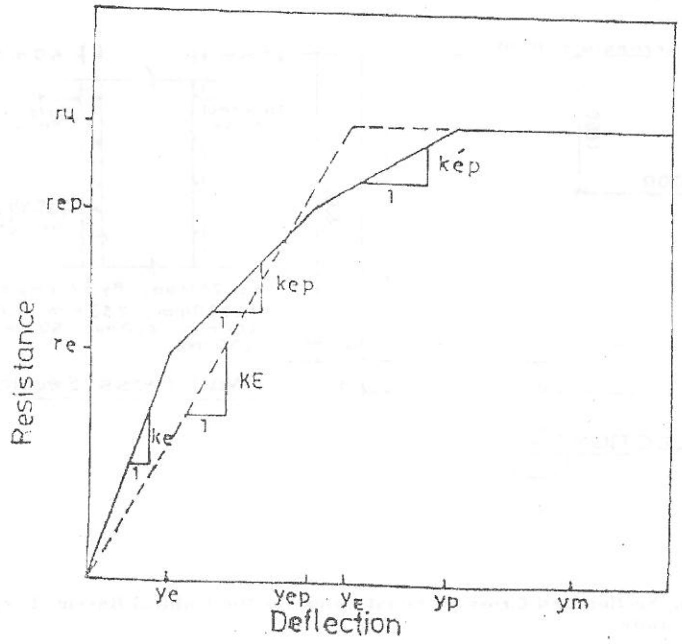

Fig.(2b): Resistance – Deflection Function for Three Step Elasto Plastic System.

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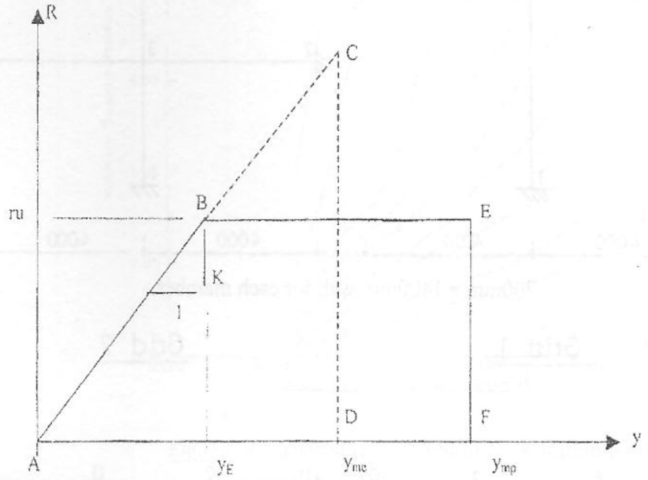

Fig. (3) Estimation of Non-Linear Response Using Energy Balance Method

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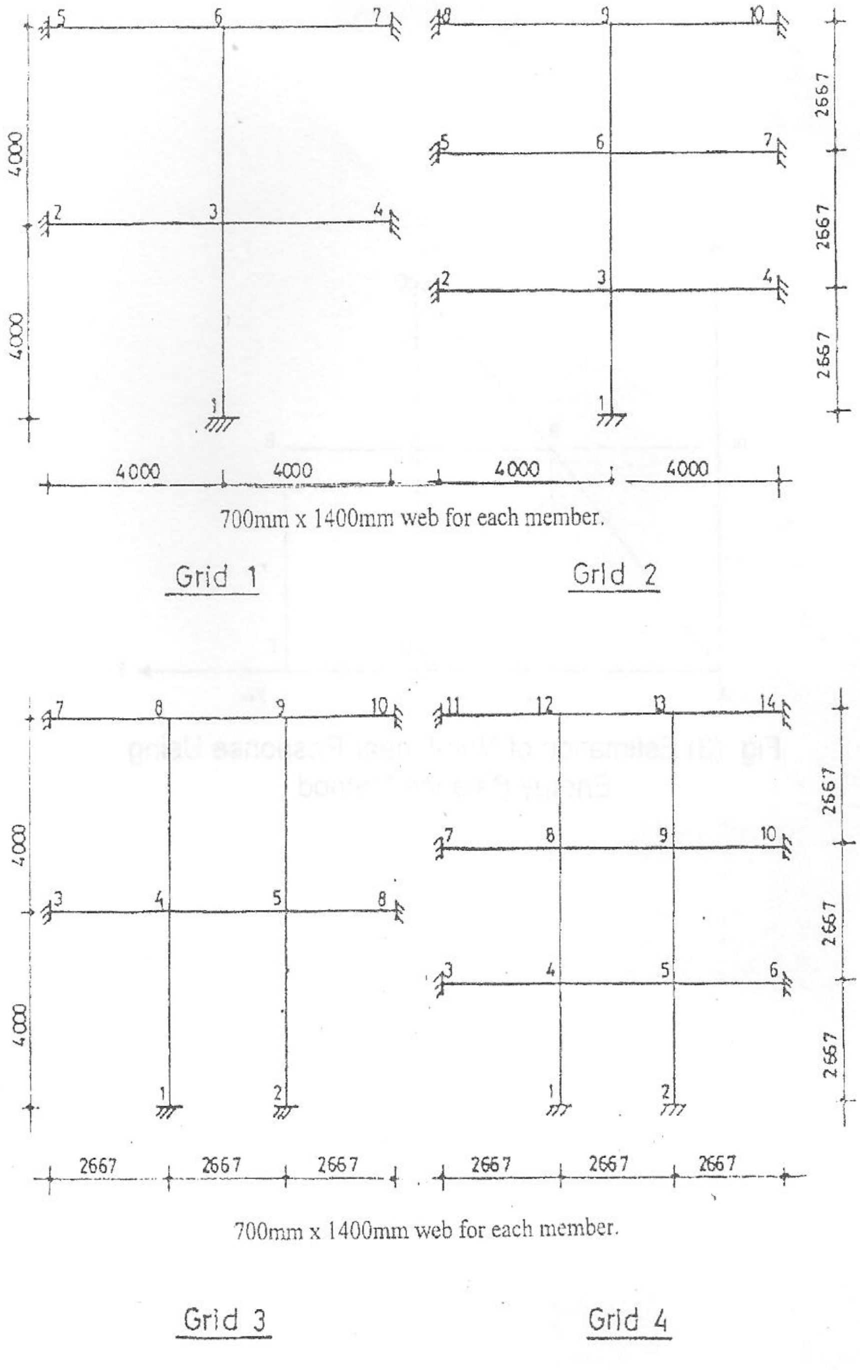

Fig.(4): Idealized Grillages for Cubicle Type II.

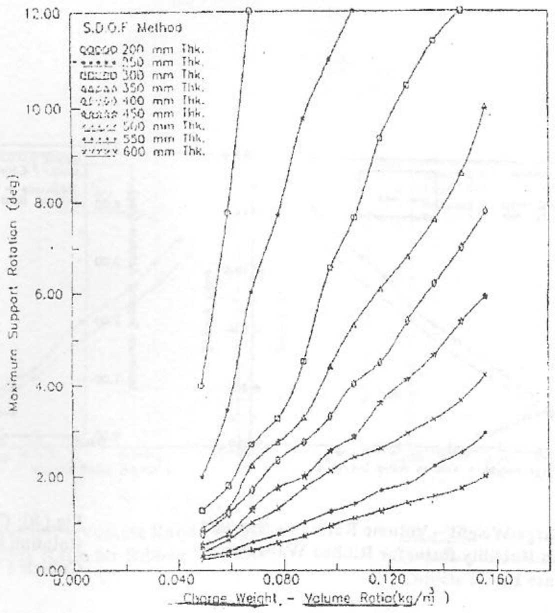

Fig.(5): Maximum (Plastic) Support Rotation for Flat Sided Walls.

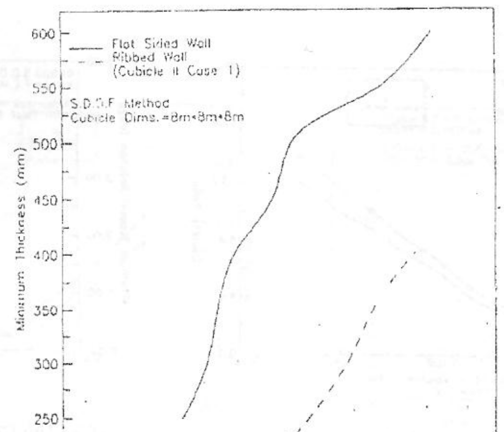

Fig.(6): Maximum Thickness Required Without Using Lacing Reinf. Vs. Charge weight –Volume Ratio.

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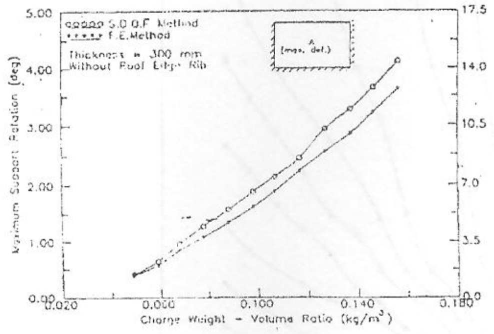

Fig.(7): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle I Case 1 .

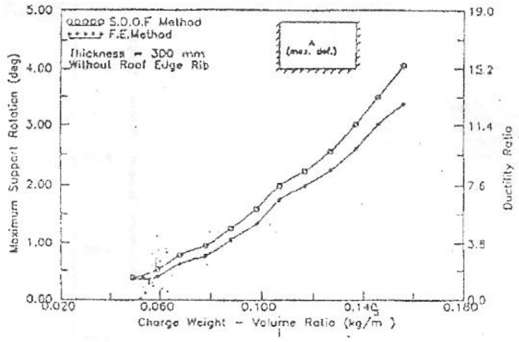

Fig.(8): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle I Case 2.

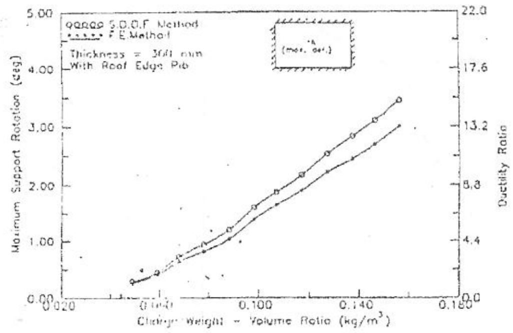

Fig.(9): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle II Case 1.

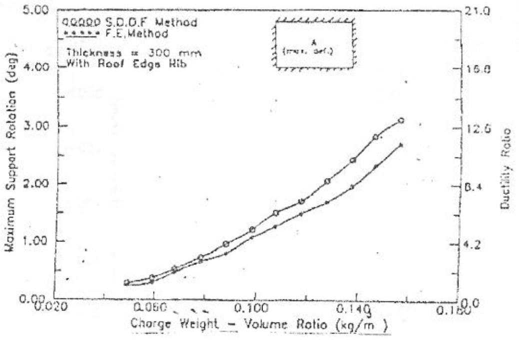

Fig.(10): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle II Case 2.

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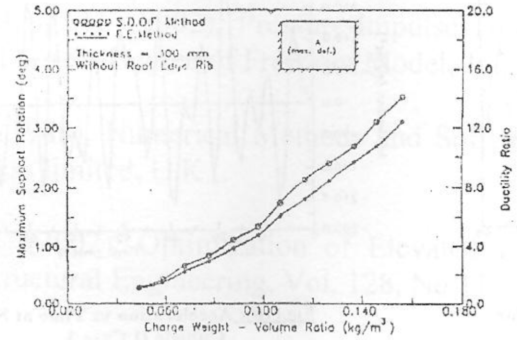

Fig.(11): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle I Case 3 .

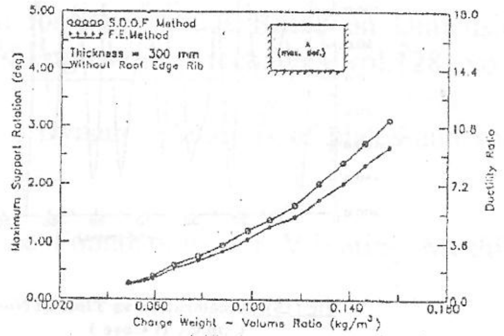

Fig.(12): Charge Weight – Volume Ratio . vs. Suppo Rotation and Ductility Ratio for Ribbed Walls for Cubicle I Case 4.

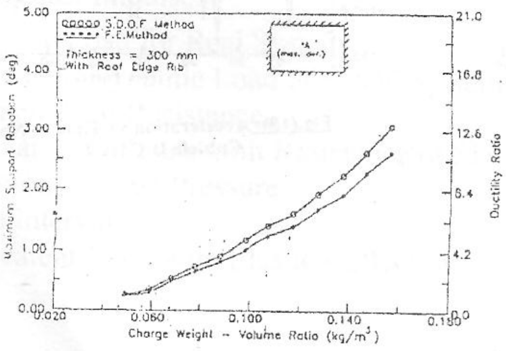

Fig.(13): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle II Case 3.

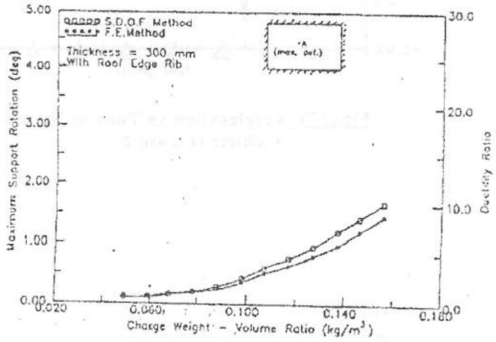

Fig.(14): Charge Weight – Volume Ratio . vs. Support Rotation and Ductility Ratio for Ribbed Walls for Cubicle II Case 4.

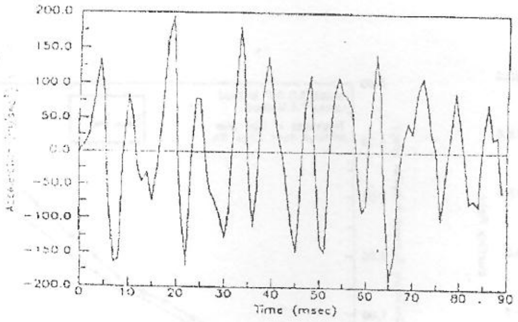

Fig.(15): Acceleration vs Time at Node 3 for Cubicle II Case 1 .

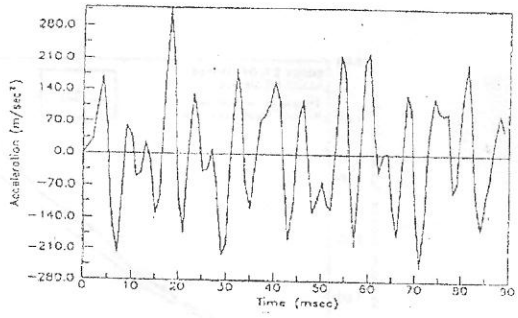

Fig.(16): Acceleration vs Time at Node 4 for Cubicle II Case 3 .

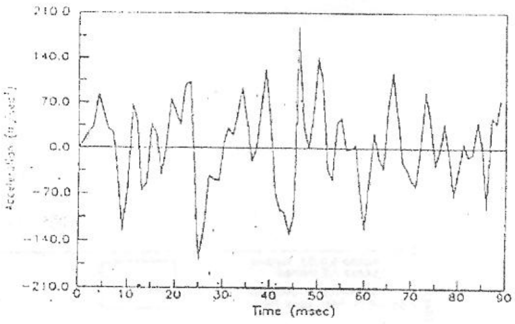

Fig.(17): Acceleration vs Time at Node 6 for Cubicle II Case 2 .

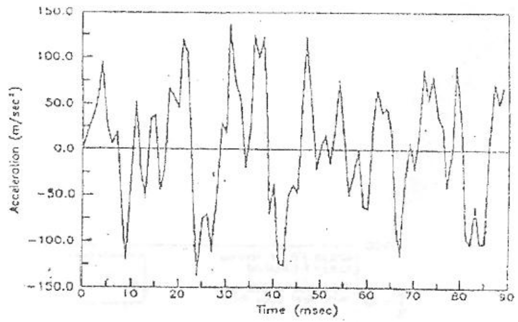

Fig.(18): Acceleration vs Time at Node 8 for Cubicle II Case 4 .

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List of Symbols

i_b Total Blast Impulse.
$P_{(t)}$ Dynamic Load for Real System.
$P_{e(t)}$ Equivalent Dynamic Load of SDOF System.
r_u Ultimate Unit Resistance.
r_{ue} Equivalent Ultimate Unit Resistance of SDOF System.
t_d Duration of Blast Pressure.
Δt Time Interval.
y_E Equivalent Maximum Elastic Deflection.