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Behavior Factor of Flat double-layer Space Structures

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***Abstract*—**Flat double-layer grid is from category of space structures that are formed from two flat layers connected together with diagonal members. Increased stiffness and better seismic resistance in relation to other space structures are advantages of flat double layer space structures. The objective of this study is assessment and calculation of Behavior factor of flat double layer space structures. With regarding that these structures are used widely but Behavior factor used to design these structures against seismic force is not determined and exact, the necessity of study is obvious. This study is theoretical. In this study we used structures with span length of 16m and 20 m. All connections are pivotal. ANSYS software is used to non-linear analysis of structures.

***Keywords*—**Behavior factor, Double-layer, Intensified resistance, Non-linear analysis

I. INTRODUCTION

THERE is high risk of seismic occurrence in most of world's countries and strong earthquakes cause human and financial losses in some countries yearly, so it is necessary to prepare codes to design earthquake resistant structures with enough accuracy and safety factor.

Discussing about various methods of structural analysis and selecting various factors of design in these codes is inevitable.Only a nonlinear dynamic analysis is representative of exact and real behavior of structures during earthquake events but this type of analysis is very time-consuming and expensive, so using of this method to analyze and design of structural frames is not practical.

Besides analyze and design of structure only based on elastic behavior without considering plastic behavior and energy absorbing or repelling capacity of structures during large earthquakes that are non-permanent and hazardous forces result in non-economical design with very heavy members.

In order to considering positive effects of plastic behavior of structures to carry lateral forces almost all of authorized world's codes use special factor called behavior factor of structure or reflection corrective factor to decrease calculated seismic forces and allows designers to perform elastic analysis of structure under reduced forces and design based on that results.

This factor is function of various factors for example ductility of structure, material property, damping characteristics, non-structural member participation, structural degree of indeterminacy, members extra resistance, members over design.

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Over few last decades method of calculating this factor for different structural systems was not specified and its value was specified based on engineering realization and guess of committee members of code preparation from behavior of structural systems. But over last few years some researchers proposed reasonable and reliable methods to calculate behavior factor. Basis of all methods of behavior factor calculation is force or energy level that a frame absorbs from first plastic hinge formation to reaching fully collapsible mechanism [1].

II. FINIT ELEMENT MODELING

A. Determining required elements

There are different elements with different specifications to perform various analyses. In this study we used Beam189 that is beam element based on Timoshenko beam theory. This element is suitable for non-linear problems. By specifying any cross- section geometric properties is calculated automatically.

B. Material property

It is customary to model steel behavior as stress-strain curve approximated by two straight lines. First line from origin with slope of E connects to point of yielding. To consider strain hardening behavior of steel second line is approximated by line with slope 5 % of initial stiffness. Modulus of elasticity and Poisson ratio of steel is 2.1E6, 0.3 respectively.

C. Modeling

Geometry of model by using FORMAIN software is created then is imported to ANSYS. After assigning elements to geometry, model is ready to analysis, but first structure is analyzed and designed [2].

D. Loading

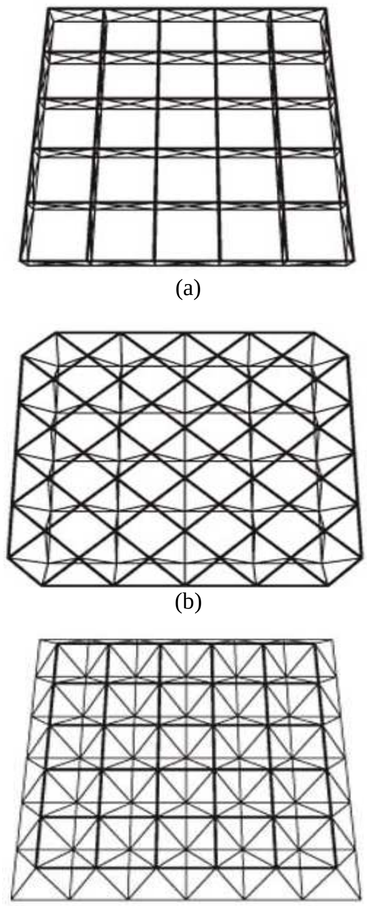
Now we specify supported nodes then constraint all translational degrees of freedom. Loads are imposed on top layer nodes. According to analysis type, it is necessary that value of loads is greater than critical load of structure, so during analysis load will be imposed increasingly to reach to critical load that solution will be divergent.

E. Solution control

Nonlinear static analysis is selected. Large displacement and arc-length method with convergence control based on limit point is used. To obtain behavior factor we need solution up to limit point.

III. MODEL SELECTION

In this study behavior factor is calculated for three models A, B, and C with plan view shown in Fig. 1. Each model has span of 16m and 20m and height of 2m, 2.5m, and 3m. Totally 18 different models is analyzed. Properties of models are shown in table I.



(a) (b) (c)

Fig. 1 Selected models (a)model A, (b)model B, (c)model C

TABLE I
SPECIFICATION OF MODELS

model	thick (mm)	dia (mm)	height (m)	long (m)	wide (m)
A	4,5	8,10	2,2.5,3	16,20	16,20
B	4,5	8,10	2,2.5,3	16,20	16,20
C	6,4	12,8	2,2.5,3	16,20	16,20

IV. CALCULATION OF BEHAVIOR FACTOR

Redistribution of lateral force causes increase in structural resistance. Extra stresses transfer from yielded members to not yielded members and load-bearing capacity of structure increases. According to mechanism type in designing based on demand and ductility capacity, the objective of design is to create enough resistance and stiffness for structure so that ductility demand of design earthquake exceeds from ductility demand of structure. Design is based on evaluation of existed ductility demand and capacity by considering nonlinear behavior of structures. Intensified resistance is important factor in determining behavior factor. Behavior factor is equal to ratio of base shear related to overall yielding of structure to base shear related to creation of first plastic hinge and shows value of resistance stored in structure because of various factors and delays collapse of structure.

In multi-degrees of freedom structure, with increase in earthquake force stiffness of structure due to creation of plastic hinge and reduced degree of indeterminacy decreases and input energy is absorbed by inelastic deformation so that structure becomes instable and collapses. Intensified resistance of structure depends on various factors such as material type, structure geometry, design code, structural details, and story numbers. Practical way to determine intensified resistance factor of space structures is performing nonlinear analysis that can be representative of specifications of structure that subjected to seismic motion and can be used to determine ductility and collapse mechanism of structure. First, we apply lateral forces along with base shear and record them continuously. This trend continues so that first structural element yields as plastic hinge, after this stage redistribution of forces cause absorbing of more lateral forces. Lateral forces increases again so that plastic hinge creates in other members. When analysis stops that structure is mechanism or its displacement exceeds allowable limits or one of elements buckles. In this point we obtain intensified factor by dividing maximum force imposed on frame to force value corresponding to first yielding of frame. Fig. 2 shows overall behavior and elastic and inelastic response of ordinary structure based on nonlinear analysis. Based on Fig. 2, we define seismic force reduction factor as:

$$R_\mu = \frac{C_{eu}}{C_y} \tag{1}$$

$$R_s = \frac{C_y}{C_s} \tag{2}$$

$$R = \frac{C_{eu}}{C_s} \tag{3}$$

Where R is behavior factor, R_μ is ductility factor and R_s is intensified resistance factor, C_y is yielding resistance or secondary resistance, C_s is elastic resistance, and C_{eu} is maximum elastic resistance.

According to (1)-(3) below definition of behavior factor is obvious [3]:

$$R = R_\mu \times R_s \tag{4}$$

Method used here is developed by Pauley and Pristley that assumes yielding force of frame V_y is known. Elastic curve obtains based on secant stiffness from force-displacement curve in force corresponding to $0.75V_y$ [4].

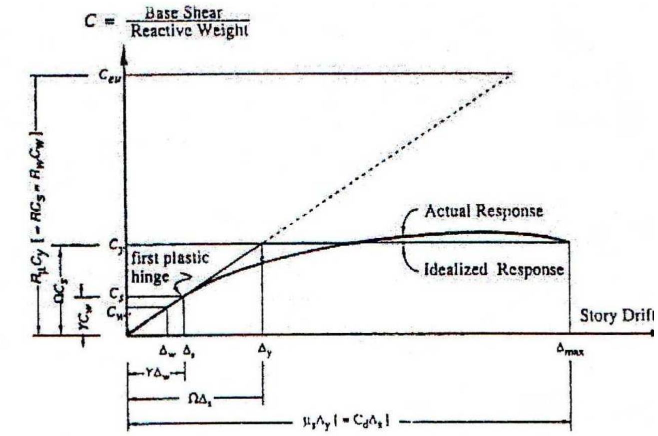


Fig. 2 Response of structure

V. Nonlinear Analysis

ANSYS software in 1971 is created by American corporation Swanson as pioneering finite element software and used here to perform nonlinear analysis. In this analysis material and geometric nonlinearity is considered. Load-deflection curve obtained from analysis for different models is shown in Figs. 3-5

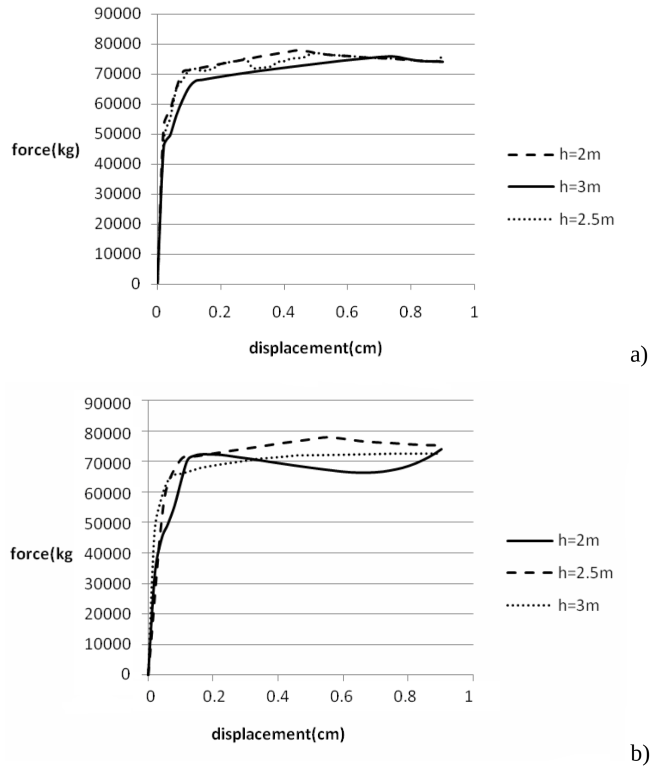


Fig. 3 Load-deflection curve of model A (a)span=16m (b)span=20m

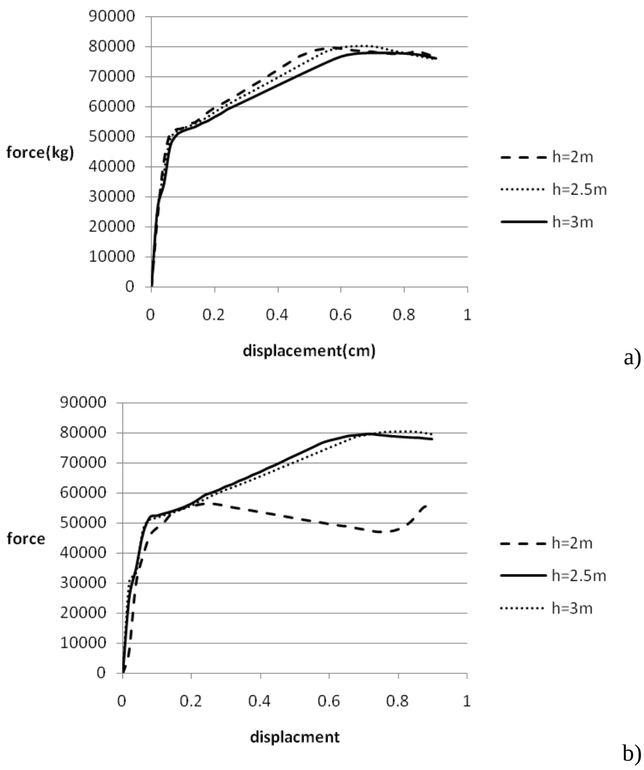


Fig. 4 Load-deflection curve of model B (a)span=16m(b)span=20m

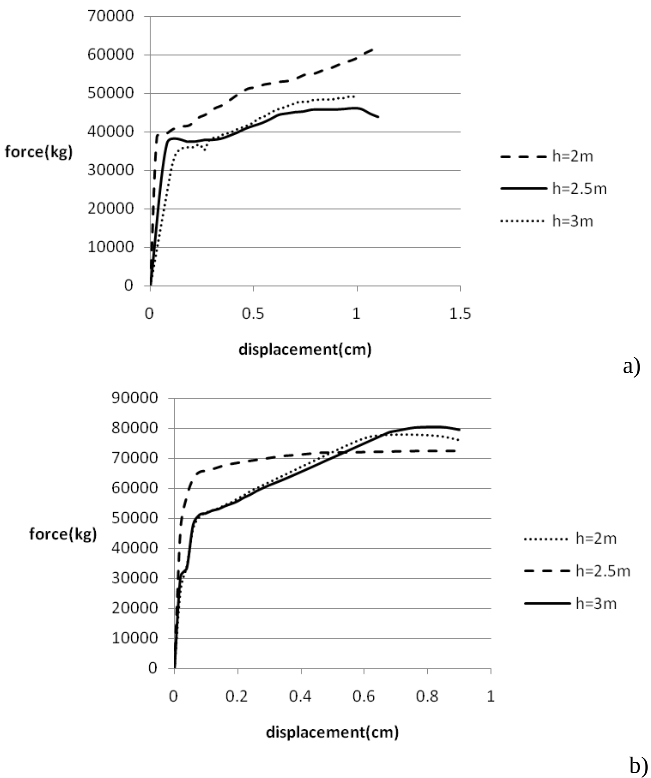


Fig. 5 Load-deflection curve of model B (a)span=16m (b)span=20m

VI. Numerical Results

By using method mentioned in section IV and nonlinear analysis results, we can obtain behavior factor.

As an example behavior factor of model A with span of 20m and height of 2m is calculated. Behavior factor of all models is introduced in tables II, III, and IV. Also, variations of behavior factors with h/d ratio are shown in Fig. 7.

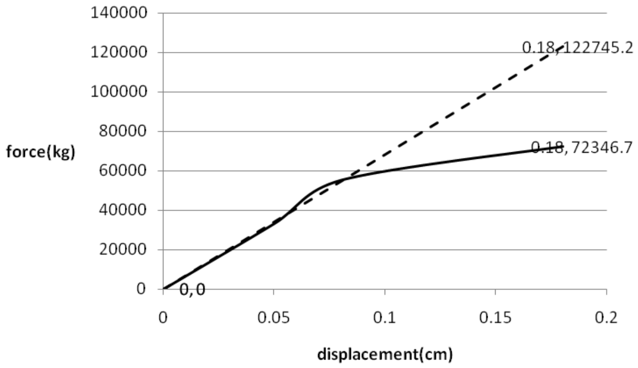


Fig. 6 Calculation of behavior factor for model A

Intensified resistance is: $R_s = C_y / C_s$ = 72346.7 × 0.75 / 33283.2 = 1.63. Ductility behavior is: $R_\mu = C_{eu} / C_y$ = 122745.2 / 72346.7 × 0.75 = 2.26. Finally, behavior factor equals to: $R = R_S \times R_\mu = 1.63 \times 2.26 = 3.68$.

TABLE II
BEHAVIOR FACTOR OF MODEL A

model geometry	intensified resistance	ductility factor	behavior factor
h=2m,D=16m	1.12	2.74	3.06
h=2m,D=20m	1.63	2.26	3.68
h=2.5m,D=16m	1.17	2.95	3.46
h=2.5m,D=20m	1.09	3.12	3.14
h=3m,D=16m	1.24	3.11	3.85
h=3m,D=20m	1.15	3.85	4.42

TABLE III
BEHAVIOR FACTOR OF MODEL B

model geometry	intensified resistance	ductility factor	behavior factor
h=2m,D=16m	1.54	3.16	4.87
h=2m,D=20m	1.36	3.03	4.12
h=2.5m,D=16m	1.24	3.17	3.93
h=2.5m,D=20m	1.18	3.81	4.52
h=3m,D=16m	1.42	3.27	4.62
h=3m,D=20m	2.08	2.44	4.9

TABLE IV
BEHAVIOR FACTOR OF MODEL C

model geometry	intensified resistance	ductility factor	behavior factor
h=2m,D=16m	1.39	2.12	2.94
h=2m,D=20m	1.04	2.71	2.84
h=2.5m,D=16m	1.94	1.98	3.84
h=2.5m,D=20m	1.05	2.72	2.86
h=3m,D=16m	1.49	2.02	3.01
h=3m,D=20m	1.31	3.13	4.12

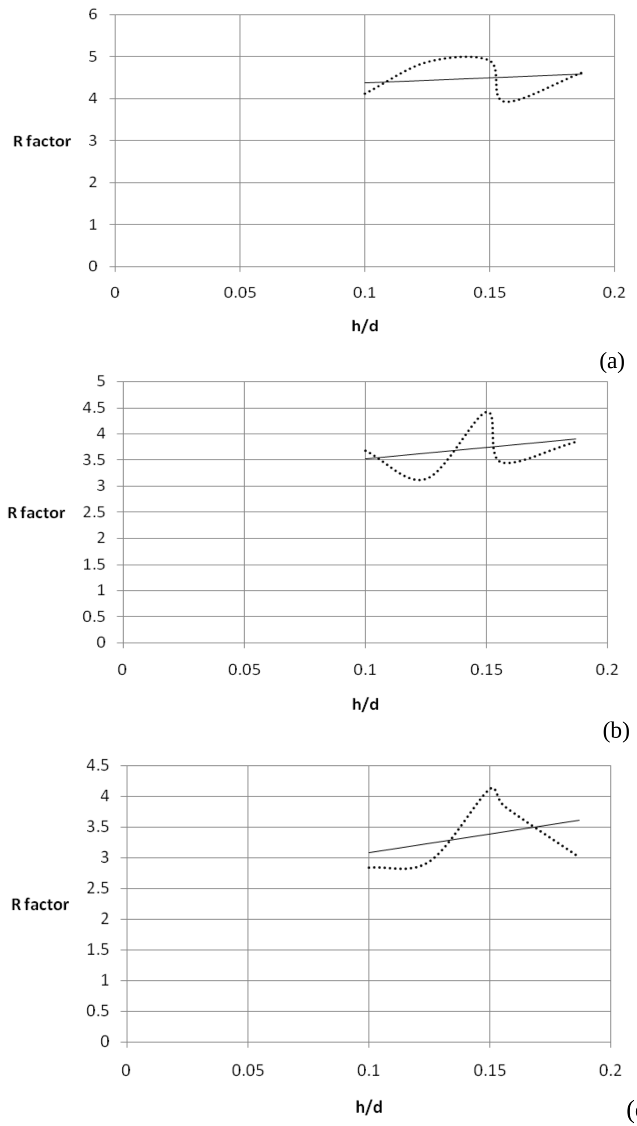


Fig. 7 Variation of behavior factor with h/d ratio (a) model A (b) model B (c) model C

VII. CONCLUSIONS

- Average value of behavior factor in 18 model is 3.37 so it is possible introduce value of 3.5 obtained from this study for flat double layer grids.
- In specific interval, structures have maximum absorption of energy. In this study for these models is from h/d=0.125 to h/d=0.156.
- With regard to curves, increase in height-to-span ratio cause increase in behavior factor.

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