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Slabs with Hidden Beams, Facts and Fallacies

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ABSTRACT— ***Local and perhaps regional vernacular reinforced concrete building construction leans heavily against designing slabs with imbedded hidden beams for flooring systems in most structures including major edifices. The practice is popular in both framed and in shear wall structures. Hidden beams are favored structural elements due to the many inherent features that characterize them; they save on floor height clearance, they also save on formwork, labor and material cost. Moreover, they form an acceptable esthetic appearance that allows for efficient interior space partitioning. Hidden beams have the added advantage of clearing the way for horizontal electromechanical ductwork. However, seismic considerations, in all likelihood, are seldom addressed.***

The mentioned structural system of shallow beams is adopted in ribbed slabs, waffle slabs and at times with solid slabs. Ribbed slabs and waffle slabs are more prone to hidden beam inclusion due to the added effective height of the concrete section.

In the following study the structural influence of hidden beams within slabs is thoroughly investigated. The investigation tackles, inter alias, deflection, bending moment distribution between beam and slab as well as its impact on relevant seismic parameters during earthquake ground excitation thus assessing the vulnerability of such structural systems. Furthermore, the following parametric study is extended to focus on medium size three reinforced concrete structures that differ in their respective flooring systems. The present study is a comparative one among various slab systems that include slabs with drop beams, ribbed slabs and solid slabs with hidden beams. Natural frequencies and Mass Participation Factors are compared; both values are fundamental for the number of characteristic modes necessary for inclusion in the analysis.

Numerical results point in the direction that the function of hidden beams is not as adequate as desired. Therefore it is strongly believed that they are generally superfluous and maybe eliminated altogether. Conversely, shallow beams seem to render the overall seismic capacity of the structure unreliable. Such argument is rarely manifested within linear analysis domain; a pushover analysis exercise is thus mandatory.

Keywords— Drop Beams; Hidden Beams; Flat Slabs; Seismic Behavior

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1. STATEMENT OF THE PROBLEM

Hidden beams are quite popular and form an essential part of modern reinforced concrete framed structures. The idea emanates from strict architectural considerations. They provide better height clearance and simplify internal partitioning. This is in addition to removing potential obstacles in the way of electromechanical duct works. Furthermore, it is noticed that thorough discourse about their structural efficiency is hitherto lacking. This applies to their performance under static as well as dynamic loadings; albeit modern structures are necessarily code required to be earthquake safe.

The following is a numerical study targeting a capability assessment of such structural elements. The undertaking investigates the following different slab scenarios and topologies:

1. Solid slabs on drop beams
2. Solid slabs with imbedded beams
3. Solid slabs with no beams
4. Two way ribbed slabs with hidden beams.
5. Two way ribbed slabs with no beams

Such elements form a part of a framed structure with one-way slabs as the primary flooring system in which wide and shallow beams constitute a characteristic feature; their width is usually larger than the size of the supporting column and their depth is normally equal to the depth of the rest of the slab. Moreover, it is safe to presume that such beams have a high reinforcement ratio particularly at the column connection to compensate for the insufficient effective depth; hence ductility is a diminished inherent feature. Since such beams are not fully supported on columns renders the spandrel connection capacity unreliable, short of an adequate torsion design. Furthermore, the orthogonal direction is more vulnerable since the beams in this direction are either narrower, so called tie beams or not present at all which places a higher strength demand on the joists alone. The strut force developed within the beam-column element is considerably high due to its shallow nature. Finally, it is justifiable to make the added presumption that the overall seismic strength and the stiffness of the building are compromised.

6. THE SLAB NUMERICAL MODELS

The selected topology for the present undertaking is arbitrarily comprised of 6 equal spans in one direction and 4 spans in the orthogonal direction. The span lengths are all equal; they are of 9 meters length in one direction and 6 meters in the other. Live loads of 5 KN per square meter are equally distributed. No load combinations are necessary for the present purpose. Models are intentionally made similar for better and easier comparison. The numerical models are constructed using SAFE of Computers and Structures Incorporation. Slab thickness in all models is set to 23 cm which is in compliance with the American Concrete Institute code requirements.

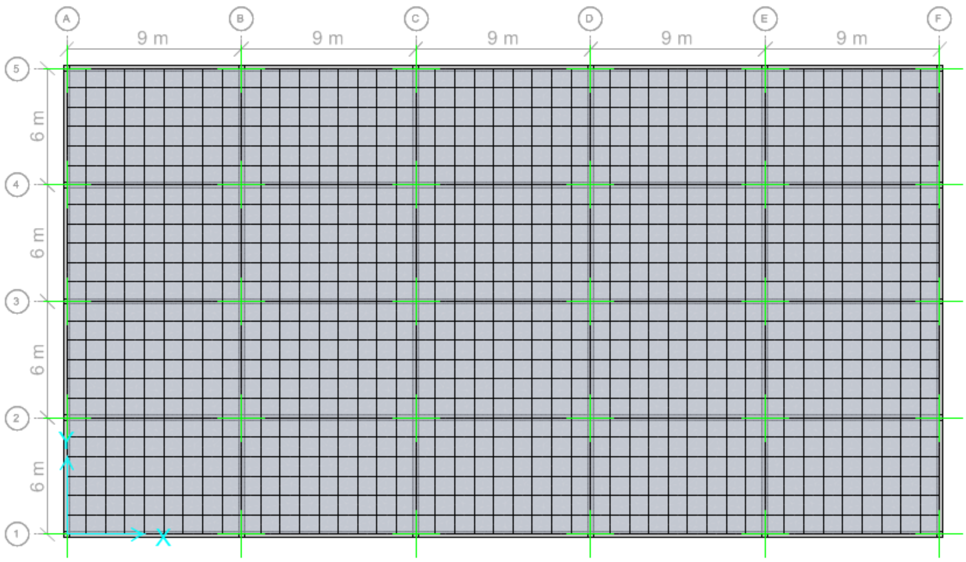

Figure 1: Slab system plan

Model 1: The slab has a depth of 23 centimeters; the beams, spanning in both directions, have a total depth of 60 centimeters and a width of 30 centimeters. The columns are square of 30 cm width. This is the model used as a basis for subsequent comparison.

Model 2: In model 2 the same topology is selected with the exception that all interior beams are made shallow with a width of 100 centimeters.

Model 3: Model 3 is the same as models 1 and 2 but with no interior beams. Strict flat plate flooring.

Model 4: In this model ribbed slabs are introduced. Each rib has a web width of 15 centimeters and a total depth of 23 cm. The flange thickness is 6 cm while the center to center rib spacing is 55 cm. The width of the supporting hidden beams is 100 cm. The dimensions are selected based on mundane local practice.

Model 5: This is the same as Model 4 yet the hidden beams are totally eliminated with two-way waffle slabs.

Furthermore, in order to investigate the structural behavior of hidden beams within the context of framed environment, three medium size structures are modeled using Etabs; they are symmetric and regular, thus avoiding possible twisting action; one structure involves hidden beams and one-way slab flooring system while the second has regular drop beams; in the third selected structure flat slabs form the flooring system. Side walls are excluded since zero or low density exterior walls are becoming the common feature of modern structures.

Dynamic behavior is also investigated by examining the basic dynamic parameters that prescribe the behavior of any structural and ultimately its structural response. Such parameters include the eigen-values, its distribution and the associated eigenvectors.

7. SUMMARY OF RESULTS

The tables below are self explanatory; e.g. Table 1 below that the share of the shallow beam of model 2 is quite small in comparison with the deep beam of model 1. Models 3 and 5 are quite similar. The results of Table 2 show that models 2 and 3 are quite similar which implies that beams imbedded in slabs make little if any contribution towards added stiffness.

Within a structure environment it is noticed that a system with hidden beams does not offer added advantage over a system in which hidden beams are eliminated and replaced a flat slab. The same argument is manifested in deflection readings. Flat slab deflection is about the same as hidden beam deflection.

Table 1: Bending Moment at a typical interior span due to live loads [KN-m]

		Model 1	Model 2	Model 3	Model 4	Model 5
Longer Span	positive	51	16	54	28	54
	negative	-87	-37	-125	-60	-133
Shorter Span	positive	26	11	33	20	41
	negative	-62	-30	-97	-45	-110

Table 2: Fundamental frequency distribution

Model	Fundamental Circular Frequency, rad/sec				Mid-point Deflection at end span (mm)
Model 1	38.5	41.63	42.5	45.3	3.94
Model 2	32.3	34.6	38.3	40.2	6.05
Model 3	32.8	35.1	39.2	40.3	7.10
Model 4	30.0	32.3	33.8	35.9	2.84
Model 5	29.7	31.7	34.7	36.0	14.3

Table 3: Fundamental Period of the 3 Structures

Model	With Hidden Beams	Flat Slabs	With Drop Beams
Mode 1	1.8009	1.2311	1.0350
Mode 2	1.1474	1.1790	0.8738
Mode 3	1.1347	0.9180	0.7726
Mode 4	0.5385	0.3996	0.3516
Mode 5	0.3937	0.3853	0.2943

8. PUSHOVER ANALYSIS

In order to further explore the behavior of shallow beams a three dimensional Pushover Analysis is invoked because many response characteristics cannot be obtained from standard linear elastic or dynamic analysis. Linear analysis is a code descriptive method suitable for low intensity loads; this route becomes irrelevant in a strong seismic event. In pushover analysis the structure is subjected to monotonically increasing lateral forces until a target displacement is reached. In the present case a 50 cm control target displacement at the top floor is set in order to get better knowledge on potentially brittle elements. For the present discourse the focus is on the beam-column connections and the axial force demand on supporting columns. This is when performance based seismic engineering is combined with seismic hazard assessment to compute the seismic performance. The following result is obtained and shown in Figure 2. The result is obtained after plastic moment hinges are defined at the beam edges where the expected large reinforcement ratio at such localities would render the shallow beams as brittle. It is clearly noticed that the ledger periphery deep beams are in IO [Immediate Occupancy] range while the hidden beams are already beyond CP [Collapse Prevention] range. Such observations remain obscured within the realm of a linear analysis discourse. Such an analysis usually leads to design modifications that better ensure life safety structural performance under seismic design.

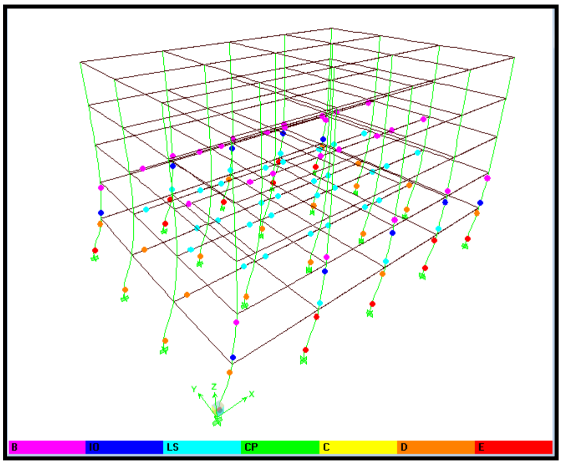

Figure 2: Pushover analysis results

9. CONCLUSION AND RECOMMENDATIONS

Based on the numerical exercise performed on the different slab systems alone and on the various flooring systems within similar structures it is noticed that in comparison with the system of drop beams, selected as a comparison basis, hidden or imbedded beams provide little, if any, added value. It can be concluded that shallow beams are vulnerable to seismic action and their behavior is questionable. This is addition to the fact that even under static loadings a hidden beam behaves more of a slab than of a beam. The foregoing results indicate that the selection of shallow beam elements within a structural system is a judicious choice that requires a thorough in-depth analysis within the context of the overall structural behavior. Linear discourse is illusive and could be misleading as it may lead to erroneous results. The present study indicates that the use of shallow beams demands focused attention, proper in depth analysis and meticulous detailing.

10. REFERENCES

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