STRUCTURAL FORM FOR EARTHQUAKE RESISTANCE

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Synopsis

For earthquake resistance the form of the structure is of fundamental importance. This paper discusses a set of guidelines which should be observed by designers in planning the form of the structure. Discussion and development of the subject is important amongst engineers and architects.

Introduction

Many engineers recognise that structural form is of great importance for earthquake resistance. It is therefore somewhat surprising that this aspect of design has not been discussed in the literature as a subject in its own right until now. This paper attempts to summarize a more comprehensive discussion given elsewhere by the author (Ref.1), of some guidelines which are regarded by many earthquake engineers as good practice.

This paper applies to all types of structure, but for buildings the importance of the understanding and co-operation of the architect and engineer in creating a sound earthquake-resistant structure cannot be over-emphasized. The designers should ensure that the structure is:

(i) simple,
(ii) symmetrical,
(iii) not too elongated in plan or elevation
(iv) uniform and continuous in its distribution of strength,
(v) structured so that its horizontal members form hinges before its vertical members,
(vi) stiff in order to reduce damage to non-structure,
(vii) not resonant with the subsoil,
(viii) suitably arranged at foundation level to ensure the validity of the analysis,
(ix) physically defined such that all elements that will interact appreciably in earthquakes are included in the analytical model.

A brief discussion of the above rules follows.

Simplicity and Symmetry

Simple and symmetrical structures (Fig. 1) have a high survival rate in earthquakes. There are two main reasons for this. Firstly, our ability to understand the overall earthquake behaviour of such structures is markedly greater than it is for complex ones. And secondly, our ability to understand structural details is considerably greater for simple details than it is for complicated ones.

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The Overall Shape should not be too Elongated

The longer a structure is in plan, the more chance there is of different earthquake movements being applied simultaneously to the two ends of it, a situation which is not generally analysed for and may produce disastrous results. Two or more separate buildings may be a better answer (Fig. 1).

For the elevation it seems reasonable to suggest a limited slenderness for most buildings: Height/width $<$ 3 or 4 (Fig. 2). The more slender a building the worse the overturning effects of an earthquake and the greater the earthquake stresses in the outer columns, particularly the overturning compressive forces which can be very difficult to deal with.

Uniform and Continuous Distribution of Strength

Ideally earthquake-resistant structures should be such that:

(a) the load bearing members are uniformly distributed,
(b) all columns and walls are continuous and without offsets from roof to foundation,
(c) all beams are free of offsets,
(d) columns and beams are co-axial,
(e) reinforced concrete columns and beams are nearly the same width,
(f) no principal members change section suddenly, and
(g) structure is as continuous (redundant) and monolithic as possible.

Perhaps the most contentious of the above items is that of uninterrupted vertical structure, but sudden changes in lateral stiffness up a building are not wise (Fig. 3) for example as shown by the damage to the Sheraton-Macuto Hotel (Ref. 2). Firstly, because even with the most sophisticated and expensive computerized analysis the earthquake stresses cannot be determined adequately. And secondly, in the present state of knowledge we probably could not detail the structure adequately at the sensitive spots even if we knew the forces involved. In investigating the 'soft storey' concept, Chopra et al (Ref. 3) found that a very low yield force level and an essentially perfectly plastic yielding mechanism are required in the 'soft' first storey, and that the required displacement capacity of the first storey mechanism is very large.

Horizontal Members should fail before Vertical

In framed building structures this is a fundamental earthquake requirement, because beams and slabs generally do not fail down even after severe damage at plastic hinge positions, whereas columns will rapidly collapse under their vertical loading once sufficient spalling has taken place.

Use Stiff Structures to reduce Damage to Non-structure

This is no doubt a controversial issue, but it is salutary to recall that over half the damage cost in the San Fernando earthquake was from non-structure. Storey drift may be reduced by diagonal bracing or shear walls (preferably ductile

Ref. 4). The Muto shear panel (Ref. 5) is a compromise between stiff and flexible solutions.

Avoid Resonance of Structure with Subsoil

This is often not possible, but where choice of storey height and flexibility exists it is worth bearing in mind the difference in resonance characteristics for different site conditions (Fig. 4), as highlighted by Seed et al (Ref. 6). This criterion may not be compatible with recommendation (vi) above.

It should be noted that the dominant period of vibration of the structure is not necessarily the fundamental period (Section 7.43.3 of Ref. 1)

The Substructure Configuration

For sites at which bedrock is not effectively at the surface, the substructure should be arranged to ensure the validity of the assumptions regarding foundation behaviour made in the seismic analysis. Usually the basic requirement is that integral action in earthquakes should be obtained. Differential and residual displacements may both need to be controlled (Fig. 5), especially in soft, loose or non-uniform soils, when using piles, or multiple pad footings.

Differentiation between Structure and Non-Structure

The distinction between structure and non-structure should be the same in the analytical model as in reality. Any elements defined as non-structure should either be of insignificant stiffness, or be detailed to ensure insignificant interaction with the structure during earthquakes. Such elements include partitions and cladding. The large difference in computed response caused by the inclusion of brick partitions in the analysis of a 20 storey building is exemplified in Fig. 6.

Conclusions

The rules suggested in this paper are understood to be followed by many practising engineers. It is hoped that this paper will help to generate discussion and development of this important aspect of earthquake resistant design.

Acknowledgement

Figures 1, 2, 3, 5, 6 are adapted from Ref. 1 with the kind permission of John Wiley and Sons.

References

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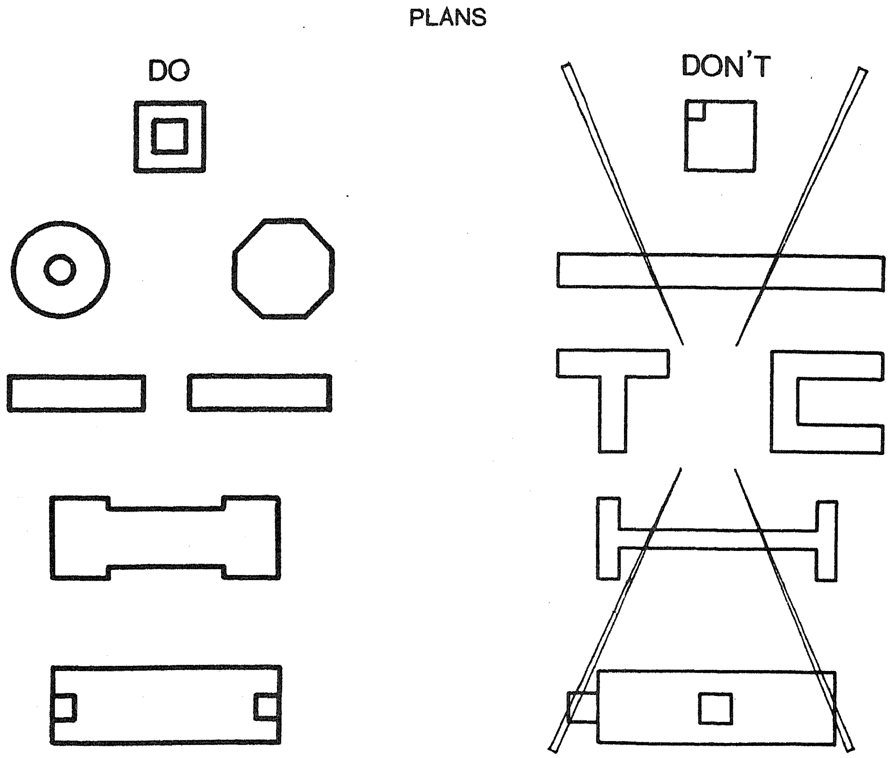


Fig 1 SIMPLE RULES FOR PLAN LAYOUTS OF ASEISMIC BUILDINGS

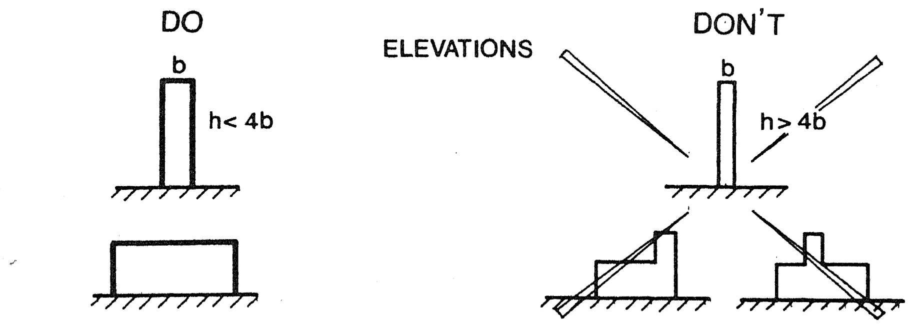


Fig 2 SIMPLE RULES FOR ELEVATION SHAPES OF ASEISMIC BUILDINGS

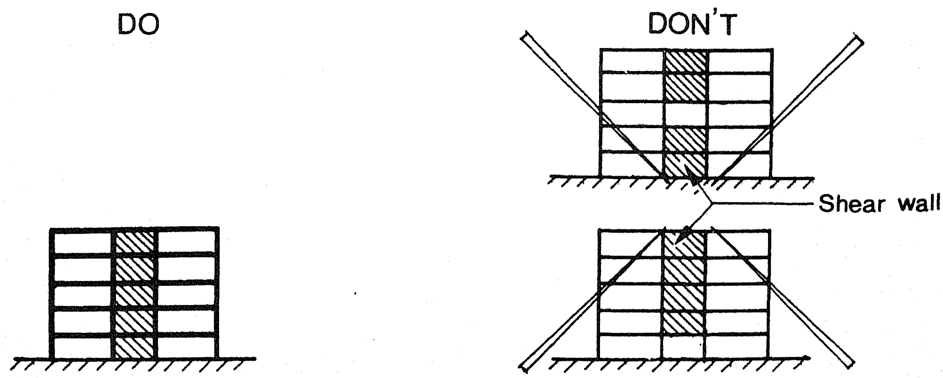


Fig 3 SIMPLE RULES FOR VERTICAL FRAMES IN ASEISMIC BUILDINGS

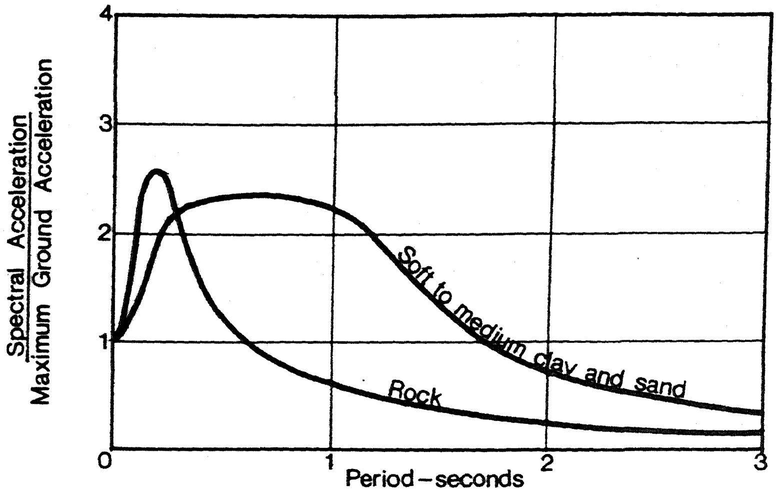


Fig 4 TYPICAL ACCELERATION SPECTRA FOR TWO SITE CONDITIONS

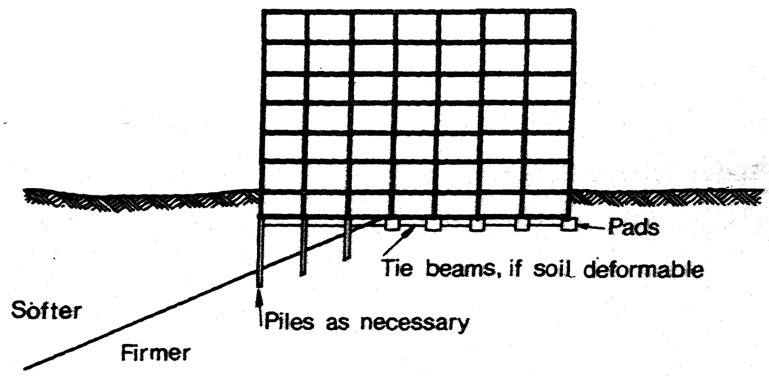


Fig 5 TYPICAL STRUCTURE REQUIRING PRECAUTIONS AGAINST DIFFERENTIAL SEISMIC MOVEMENTS

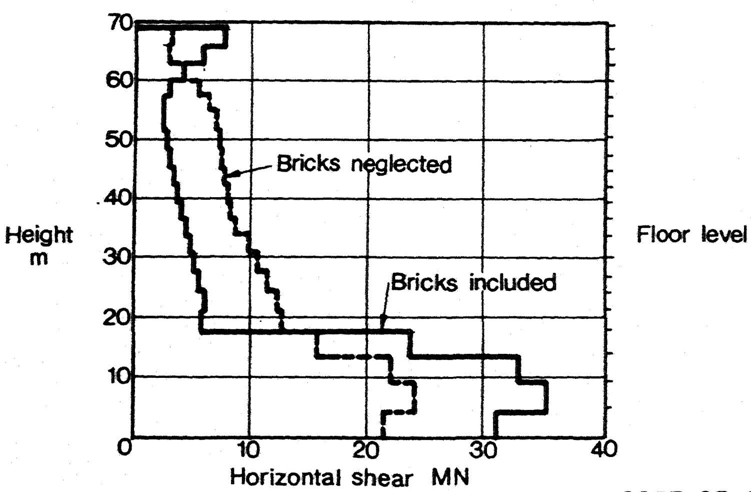


Fig 6 HORIZONTAL SEISMIC SHEAR DIAGRAM FOR LIFT CORE OF 20-STOREY HOTEL BUILDING

DISCUSSION

S.C. Gupta (India)

The paper of Mr. David J.Dowrick is illuminating and interesting. It is, however, felt that it may not always be possible to have symmetrical structures in plan and in elevation to restraints on account of site limitations and aesthetic appearance. A practical method may therefore, be to divide the unsymmetrical shape into one or more symmetrical shapes by providing joints with width enough to avoid collision of the two parts during earthquake. With this view, Fig. 2 attached indicate Don'ts and Do's.

The author has included a square plan with some central square portions open to sky as a desirable plan. This, perhaps, would be applicable if rigorous analysis is carried out to take into account the extra stiffness due to shape of the building which will make it behave like a hollow core structure and also to determine extra stresses in wings. In case, however, rigorous analysis cannot be undertaken due to limitations which many times exist in normal design offices, it would be desirable to divide the shape into simple rectangular blocks by providing joints of sufficient widths, as indicated in Fig. 3.

P. Padmanabhan (India)

Simple but important rules for earthquake resistant design of buildings, including some Do's and Don'ts are given in the paper. In Fig. 5, a building is shown resting partly on pad footings on firm soil and partly on piles passing through softer soil with end-bearing on firm soil. The author has cited this as a case where differential and residual displacements need to be controlled. The discussor is of the view that such mixed use of different types of foundation under the same building should be avoided. The arrangement shown in Fig. 5 should fall under the category of Don't. Buildings at such sites should preferably have a complete separation between the portions of the building resting on different types of foundations.

M.L. Kalra (India)

Mr. Dowrick has recommended for earthquake resistance design that beams should fail before columns. It indirectly means that columns should be stiffer than beams. Drift is also a problem in tall building whether we are considering earthquake loads or wind loads. The author's attention is drawn to a paper entitled "Drift in high rise steel framing" by John B. Scalzi - Journal "Progressive Architecture 1972". In this paper it has been stated that in case of rectangular frames subjected to lateral loads, increasing the column stiffness does not reduce the drift by appreciable amount whereas by increasing the girder stiffness by a small amount an appreciable reduction in the lateral displacement of the frame is achieved. It is recommended that in this paper girder to column stiffness ratio should be of the order 1 1/2 to 1.

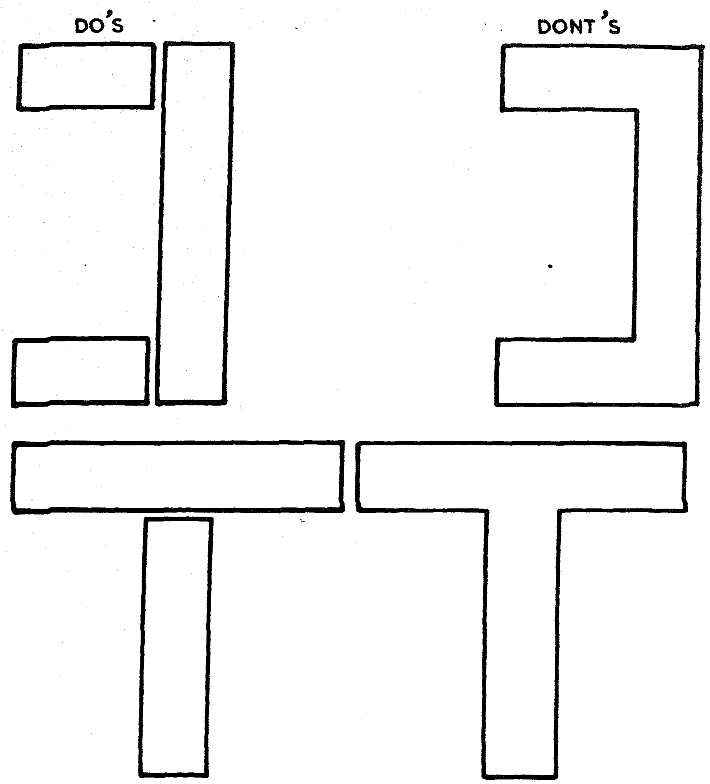
In normal design of a building for vertical loads and lateral forces the columns generally are stiffer at lower levels than beams. At higher levels the columns and beams are either equally stiff or the beams will be stiffer. It is felt that this practice is in order for an economical and efficient design for vertical and lateral loads.

The author is requested to comment on this aspect.

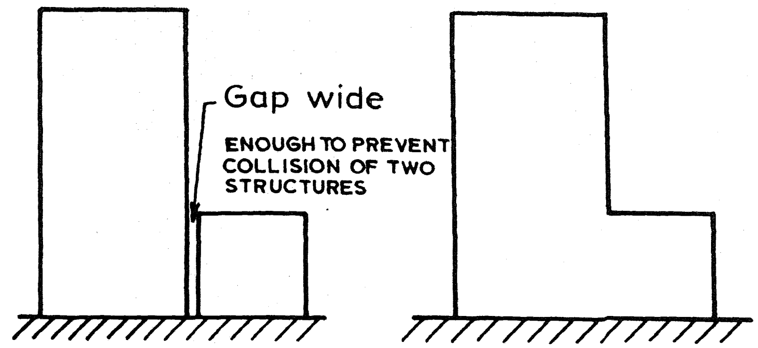
In Fig. 1, the author does not recommend the use of 'T' 'U' or 'I' type layouts of structures and has recommended symmetrical structures. The discussor agrees with these recommendations but generally the layout of buildings is governed by availability of land and functional and architectural requirements. In India the practice is that when the layout of a building changes in direction crumple joints are provided for separation. The discussor would like to invite the comments of author on this aspect.

In Fig. 2 it has been recommended that $h < 4b$. This may be all right in beam and columns construction but if shear walls are introduced we can adopt more slender structures.

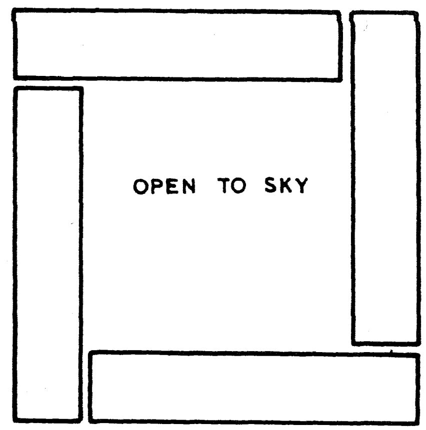
<u>Author's Closure</u>



PLAN
FIG. 1



ELEVATIONS
FIG. 2



PLAN
FIG. 3