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ASSESSMENT CRITERIA FOR EVALUATION OF LIKELY PERFORMAN CE OF LIVING ENVIRONMENT IN SEISMIC AREAS OF INDIA

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SUMMARY

Earthquake has claimed more than 48,000 lives in recent 5 major earthquakes in India (6). The large-scale destruction is attributed to the fact that the existing building stock is in an advanced state of decay and has inadequate strength to resist an earthquake and the new buildings are coming up without adequate measures as far as seismic safety is concerned. Considering the importance of restructuring and revitalization of existing built environment this paper presents a mythology, which would help in the assessment of the likely performance of the built environment in the country. Based on the survey results of last three major earthquakes in India viz. Latur earthquake of 1993, Jabalpur earthquake of 1997 and Bhuj earthquake of 2001, this empirical methodology provides a faithful and realistic picture of seismic vulnerability of building stock in developing country like India. This investigation is aimed to develop a tool which can be used to grade the quality of the existing living environment in the country in order to take necessary steps towards its restructuring and revitalization to minimize earthquake damages in future as far as possible.

INTRODUCTION

India has a long history of earthquake. About 55% of total area of the country is vulnerable to seismic activity of varying degree. The large-scale destruction demonstrated that in most of the living areas the

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living environment is highly susceptible to moderate earthquakes. More than 86 % of the building stock is consists of non-engineered buildings constructed with the use of vernacular constructional practices (6). These are basically evolved and adopted by the people under a number of socio-economic constraints. The living environment consists of two basic factors viz-seismic environment, which is a natural phenomenon and built environment, which is developed by man for his livelihood in response to the physical as well as socio-economic needs and aspirations. Indian cities/villages have a distinct character and personality, which possess typical type of built masses constructed in a peculiar manner arranged in an organic way to create characteristic space pattern indoors and outdoors. This juxtaposition of masses and spaces altogether respond to an earthquake and their performance in such an event depends on a number of structural, architectural and socio-economic aspects. In such a circumstances in order to assess the likely performance of living environment, it is necessary to consider maximum possible components that compose the total living environment besides the structural strength of the building as an isolated unit.
Introductory material

Methodology

The evaluation system, which has been adopted in this investigation, is based on a synthetic decision analysis used to identify the elements, which are largely found responsible for earthquake damages to Indian building stock. They are the type of construction, Strength of shear walls, roofing and flooring system, foundation and soil characteristics and building configuration. Each of the identified elements are further detailed out and assigned certain numerical values. Built environment index (Be) is calculated as follows:

$$Be = B\,i - \Sigma\, Cr \qquad (1)$$

In which Bi is the built form index and Cr is the correction factor corresponding to architectural /urban design elements numbering n.

$$\sum_{r=1}^{n} cr \qquad (2)$$

The seismic risk index Sr could be worked out from the formula given below

$$Sr = \frac{Be}{Z} \qquad (3)$$

In which Z is the seismic environment factor.

Determination of the numerical Values for the built-form characteristics

Based on investigation result of 120 nos. surveyed buildings in the earthquake affected area of Bachau, Gujarat five characteristic features responsible for earthquake damage were identified, which are referred here as built form factor Bi. Out of 120 studied cases 35 % suffered damages mainly because of the inadequate selection of construction type, which proved disastrous on the exposure to the earthquake. The B1 value from the survey results of Jabalpur and Latur earthquakes was obtained as 37 (6), this value is further modified and numerical value of weightage for the factor " type of construction" has been assigned as 36. Here maximum value out of 36 is indicative of the adequate strength of the structure as far as earthquake occurrence is concerned. Similarly numerical values were assigned to other identified built form factors (Bi) as shown in fig-1

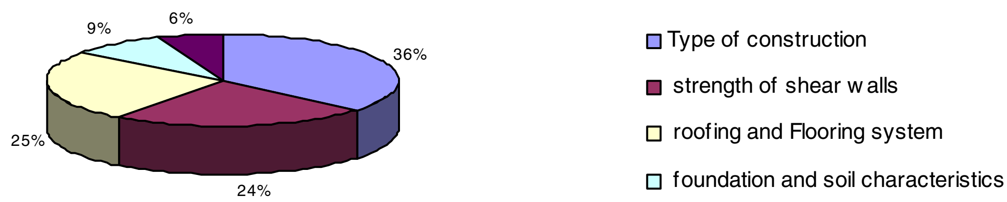

Fig.1
BUILT FORM CHARACTERISTICS

Analysis of the Built form Factors
Based on the Micro-level survey these five Built form factors are further detailed out.

Type of Construction (B1)
A number of construction systems and vernacular techniques are in frequent use in the different parts of the country irrespective of their seismic resistance (4). Out of which most commonly used in Bachau are investigated. In addition to this with reference to the performance of various construction systems in Uttarkashi, Latur and jabalpur earthquakes (6) numerical values for built form factor B1 has been assigned out of the maximum value 36 to various construction systems as shown in the table 1.

Table-1
Numerical Value for the Type of Construction

B1: Maximum Value: 36

S.No.	Type of Construction	Numerical value (B1)
1	R.C.C. framed building	32
2	Timber framed building	28
3	Partially framed building	22
4	Reinforced brickwork	20
5	Load bearing brickwork	12
6	Load bearing stonework	08
7	Adobe construction	05
8	Mud construction	03

Strength of Shear walls (B2)
The use of substandard quality materials in construction particularly the binding material resulted catastrophic failure of load bearing walls (3). More than 70% of Indian building stock consists of load bearing type of construction; in rural areas this is even more than 85% (4). Failure of shear walls in the absence of good quality mortar was one of the major reason of earthquake damages as observed in 1991, Uttarkashi and 1993 latur earthquakes which claimed more than 11,750 lives (6). The quality of binding

material which of crucial importance in load bearing construction is extremely poor as observed in majority of the cases, in fact there are a large number of cases where no mortar have been used. Such constructional practices are widely used and proved disastrous as ones again demonstrated in Bachau where 24% of the surveyed buildings suffered heavy damages because of the poor strength of shear walls. Built form factor values for built form factor B2 are worked out on the basis of quality of mortar used in the construction as shown in Table-2.

Table-2
Numerical Value for the Strength of Shear walls

B2: Maximum Value: 24

S.No.	Strength of Shear walls	Numerical value (B2)
1	Cement mortar 1:6	20
2	Cement mortar 1:8	18
3	Lime mortar	15
4	Cement mortar leaner than 1:8	10
5	Mud mortar	04
6	Walls without mortar	00

Roofing and Flooring System (B3)

Alarming rate of life and property loss attributed to this factor as was observed in past earthquakes. Failure of roof were noticed in 26 % of the cases in Uttarkashi, 28 % of the cases in Latur and 24% in Jabalpur earthquakes (6), while in Bachau 22% buildings suffered damages because of the factor B3. The numerical values for built form factor for various roofing and flooring systems B3 are shown in table-3 as follows

Table-3
Numerical Value for Roofing and Flooring System (B3)

B3: Maximum Value: 25

S.No.	Roofing and Flooring System (B3)	Numerical value (B3)
1	R.C.C. slab on R.C.C. beams	20
2	Steel trusses with A.C. sheet roofing	19
3	Timber trusses with tiled roofing	11
4	Wooden planks on wooden joists	10
5	Stone slabs on steel girders	5

Foundation and Soil Characteristics

Many buildings suffered partial as well as total collapse because of inadequate design of the foundation located in the areas having soil with poor load bearing capacity (7). It is an undeniably a fact that the large-scale damage to multistoried buildings in urban and semi urban areas of Gujarat in Bhuj 2001 earthquake was an exceptional case. In this view this factor has been analyzed in a way, which can be largely applicable to the majority of building stock that commonly exists in a typical Indian city/village. A number of foundation types in different soil condition commonly found in Bachau have been investigated. Considering the survey results of past earthquakes (6) the numerical values are assigned. Table-4 shows the assigned numerical values for the built form factor B4.

Table-4
Numerical Value for Foundation and Soil Characteristics

B5: Maximum Value: 09

S.No.	Type of Foundation	Numerical value (B4)
1	Pile foundation	08
2	R.C.C. footing on normal soil	08
3	R.C.C. footing on soils with low load bearing capacity	07
4	Spread foundation in brickwork on normal site	06
5	Spread foundation in stonework on normal site	06
6	R.C.C. footing on sloping site	05
7	Spread foundation on soils with low load bearing capacity	03
8	Spread foundation on sloping site	03

Inadequate design of the buildings with respect to their configuration in plan and elevation is one of the important factors as far as earthquake occurrence is concerned (1). Considerable damage has been observed in 6% of the investigated buildings because of this phenomenon on the basis of which numerical values that are assigned are shown in table-5.

Table-5
Numerical Value for Building Configuration (B5)

B5: Maximum Value: 06

S.No.	**Configuration characteristics**	**B4**
1	Symmetrical building	06
2	Fairly symmetrical building	05-04
3	Unsymmetrical building	04-01
4	Very unsymmetrical building	O1-00

Earthquake affects total living environment, which is a complex phenomenon, composed of many interdependent activities, services, functions, life systems and facilities (2). For its realistic assessment of likely performance on exposure to an earthquake buildings should not be seen in isolation. Indian cities/villages possess a typical form where spaces are created and used in an organic way. Sometimes closely woven built masses on streetscapes without adequate marginal open spaces which is a common phenomenon resulted in increased damages as evident in Bhuj 2001 earthquake, where hundreds of children died passing through a narrow street in Anjar (5). Generally a large number of building elements like shading devices (chajjas), railings, grills (jalies), cornices, decorative parapets, balustrades etc are just added to the main structure instead of designing them as its integral part. This phenomenon decreases the structural strength to a great extent and found responsible for earthquake damages in the form of partial and total collapse of the building parts, which have claimed many precious lives in addition, to great economic losses. Presence of such elements, which are referred here as correction factor (Cr) is directly proportionate to the extent of damage as observed in past earthquakes, and they can increase it by 20% (6). Commonly used architectural decorative elements in Indian buildings are identified and investigated in order to assign numerical values for the correction factor (Cr) as shown in fig.2.

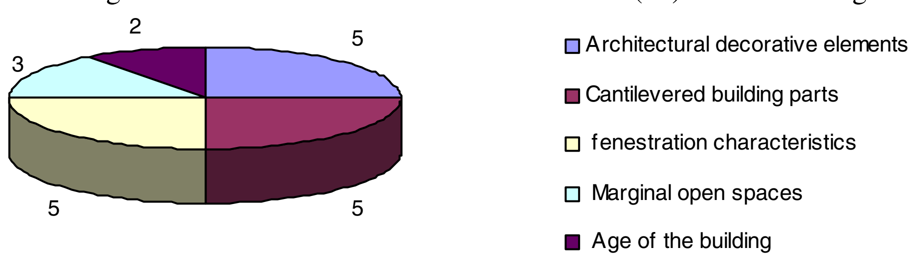

Fig.2
CORRECTION FACTOR

Being a negative aspect this value is subtracted from the built form factor to obtain Built environment index (Be):

$$Be = bi - \Sigma Cr \qquad (4)$$

With due consideration to the seismic environment of the area in question seismic index (Sr) has been determined by the following equation:

$$Sr = \frac{Be}{Z} \qquad (5)$$

Where Z is seismic environment factor the numerical values of which are shown in table-7 based on seismic zone map of India (8):

Table-7
Seismic Environment Factor

S.No	Seismic zone	Numerical Value
1	Architectural decorative elements	1

2	Cantilevered building parts	2
3	Fenestration characteristics	3
4	Marginal open spaces	4

The value of Sr thus obtained could act as rating for the assessment of likely seismic performance of a particular living environment as shown in the following table

Table-8
Rating for likely seismic performance

S.no.	Score	Grade	Seismic Performance
1	100	I	Seismically safe
2	80-100	II	Excellent measures of earthquake resistance
3	50-80	III	Good measures of earthquake resistance
4	30-50	IV	Fair measures of earthquake resistance
5	15-30	V	Poor measures of earthquake resistance
6	Less than 15	VI	Very poor measures of earthquake resistance

Conclusion

The key aspect of earthquake risk mitigation is the assessment of the likely performance of the living environment from a wider perspective. It calls for an in-depth study of Indian vernacular architecture and prevailing constructional practices on the basis of which their likely performance could be graded systematically. The present paper is aimed to develop a tool for grading the living environment in cities/villages in India where earthquake resistance is a socio-economic problem rather than a technical one, considering its various aspects, which contribute to earthquake damages by and large. The grading suggested in this investigation could be used as a basis to suggest technically efficient, economically viable and socially acceptable solutions suitable for the peculiar character of living environment in India.

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