Rationalising acceptable levels of damage for structures designed as per codes IS 456, IS 1893 and IS 13920

Discussion by Aparna K.P. and Ashok K. Jain
Reply by Swajit S. Goud and R. Pradeep Kumar

Dear Sir,

This has reference to the paper titled 'Rationalising acceptable levels of damage for structures designed as per codes IS 456, IS 1893 and IS 13920' authored by Swajit S. Goud and R. Pradeep Kumar published in the ICJ November 2015 issue (Vol. 89, No. 11, pp. 26-37).

Our observations and discussions are as follows.

Observations

1. The authors have used FEMA 356 (2000) for the analysis. The latest specifications are FEMA 440 (2005) and ASCE 41 (2006) both improve upon FEMA 356 and ATC 40 methods. Similarly, the later version of the software used by the authors (ref 10) is based on the latest FEMA documents.

2. The authors did not consider performance point or target displacement which is a very significant step in nonlinear static analysis.

Discussion: By itself a pushover analysis is too severe a loading and is purely hypothetical. That is why, the concept of performance point is very critical in analyzing the results along with interpretation of pushover analysis.

The authors reply

Static pushover analysis is a popular tool for seismic performance evaluation of existing and new structures. It will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. Simplified non-linear analysis procedures using pushover methods such as the capacity spectrum requires determination of three primary elements: Capacity, demand and performance. Demand is a representation of the earthquake ground motion. Whereas the capacity is a representation of the structure's ability to resist the seismic demand. The structure must have the capacity to resist the demand of the earthquake such that the performance of the structure is compatible with the objectives of the design. However in the current study the pushover curve is evaluated irrespective of the demand. It is considered upto the point where storey drift is 4% of height or strength degradation of 50%, whichever occurs first in the structure. Hence the target displacement is not calculated as per guidelines.

They have made the following statements and conclusions in the paper:

1(a) Under the heading **Design as per IS 13920** – Increase in R Factor lead to decrease in base shear which ultimately lead to significant amount of decrease in member dimensions and reinforcement; However, in the conclusions, they have made a ***contradictory but correct*** statement – "Seismic design though slightly expensive".

Discussion: The data provided by the authors in Table 5 does support their first statement as is summarized in the following tables.

Table 1a Based on Table 5 of the authors

Model	Design basis	Column				Beam			
		Reinforcement in tonne			Con-crete	Reinforcement in tonne			Con-crete
		Long	Shear	Total	m^3	Long	Shear	Total	m^3
IV	Normal	3.15	0.60	3.75	15.75	0.78	0.35	1.13	9.71
VIII	Ductile	1.65	0.95	2.60	15.75	0.42	0.36	0.78	9.91
V	Normal	4.16	0.69	4.85	20.53	1.01	0.60	1.62	11.90
IX	Ductile	2.13	2.03	4.17	20.53	0.70	0.67	1.37	12.73

Table 1b Summary of results

Model	Gross		% increase w.r.to normal detailed structure	
	Reinf	Concrete	Reinf	Concrete
	(t)	(m^3)		
IV	4.88	25.46		
VIII	3.38	25.66	(-) 30.7%	0.078%
V	6.47	32.43		
IX	5.54	33.26	(-) 14.37%	2.57%

Apparently, this conclusion goes contrary to the other statement made by the authors "Seismic design though slightly expensive". Nevertheless, it is also a proven understanding that there is about 10% to 20% increase in cost due to ductile detailing. In the present case, it is difficult to decode this anomaly in the absence of complete analysis and design data. The authors may please elaborate.

Reply

1(a) Member dimensions for SMRF are kept equal to or greater than OMRF (Table IV). In this the cost of building designed for seismic load increases w.r.t. increase in seismic zones (Model I–V). The cost for SMRF in zone II and III is more (Model II, VI and Model III, VII); whereas in Zone IV and V is less compared to OMRF (Model IV, VIII and Model V, IX). From the obtained results it is clear that ductile detailing is costlier for lower seismic zones (Zone II and III) whereas it is inexpensive for higher seismic zones (Zone IV and V). In ductile design due to the reduction in base shear the design force will decrease which leads to decrease in longitudinal and shear reinforcement in members. Because of special confinement provisions provided in beam and columns, the shear reinforcement in members will increase.

With the current codal provisions if the quantities steel and concrete of OMRF and SMRF (Reduced member dimensions) are compared then OMRF frame will definitely be expensive for higher seismic zone whereas it may differ for lower seismic zones.

1(b) The pushover curves for all the buildings, both normal detailed and ductile detailed, in Figure 6 show a post yield plateau corresponding to ductile behaviour.

Discussion: The normal detailed buildings are expected to exhibit a brittle behaviour without a post yield plateau. The reason being there is no confinement of concrete in the yield zones. The shear stirrups and column ties are very far apart. The normal detailed models IV and V are showing a displacement ductility of 3.7 which is quite commendable. Frame V has 1.2% drift whereas Frame IX has 1.6% drift.

So why these results are defying the conventional understanding?

Reply

Post yielding behavior of pushover curve depends on the following:

1. Confinement zones provided in members
2. The redundancy present in the structure and
3. The hinge mechanism.

While performing the pushover analysis, sudden drop down in pushover curve can be observed if hinges are first formed in the crucial members or if shear failure occurs in the members.

In the present study for normal detailed structures which are designed for gravity loads along with seismic loads for Zone II-IV, the structures have shown brittle failure. To improve the performance, the shear reinforcement in columns has been changed to satisfy the below two conditions, which is to make shear reinforcement conforming.

1. Hoops are spaced at ≤ d/3
2. Strength provided by the hoops (Vs) is at least three-fourths of the design shear

1(c) Pushover curve of two buildings designed for ductile and normal detailing having different member sizes show that ductility have increased but initial stiffness and strength was decreased in ductile detailed building.

Discussion: Table 9 gives period of vibrations. For model VIII and IX, the periods are 1 and 0.77 sec against 1.02 and 0.81 sec for models IV and V. It means ductile detailed frames are initially same or more stiff than normal detailed frames. These results are contrary to their statement.

Reply

In the statement different member sizes refer to reduced member size. Results in table 9 are shown for SMRF frame having member sizes equal or more than OMRF frame (Table IV). Results for SMRF frame having reduced member size compared to OMRF are not shown.

1(d) Seismic design though slightly expensive but when compared to the loss, the slightly more initial investment made during the construction is better than investing ***nearly 20 times more*** than the initial investment on retrofitting.

Discussion: The figure of investing 20 times more than initial investment appears to be highly exaggerated. If the building is in such a bad shape after the event, it has to be demolished. Simple. Retrofitting is recommended if the cost is less than about 20% of the cost of a new building besides depending upon various other parameters.

Reply

"Initial investment" in the above question is referred to increase in the cost due to seismic design and not the total cost of the building. For example; A building is designed for gravity load only (considering Rs. 1200/sft as construction rate), the cost of the building would be approximately Rs. 1.92 Cr. If the same building is designed for lateral loads in seismic zone III, the increase in total quantity of steel would be approximately 10 tons leading to increase in the cost by Rs. 4.5 lakhs.

"Investing 20 times more" is referring to the increase in the cost due to seismic design i.e., Rs. 4.5 Lakhs which comes out to be Rs. 90 Lakhs and not the on the original cost which is Rs. 1.92 Cr. Also the amount Rs. 90 Lakhs includes 'structural and non-structural damage'.

2(a) Under the heading **Design as per IS 13920** – Extent of damage from ductile detailing is expected to be less than normal detailing, which can be achieved by keeping initial stiffness and strength equal to normal detailed building.

2(b) Design provisions for ductile detailing need to be modified as it has been observed that with increased R value, the member sizes decrease and lead to structures having more damage compared to the normal detailing structures.

Discussion: We beg to differ with both these statements. The extent of damage in a building depends upon design, detailing and intensity of the earthquake. The seismic design philosophy is very clear in the event of minor, moderate and severe earthquakes. Since the intention of R factor is to reduce the base shear, the decrease in design force is offset by providing ductility. The building is expected to be ductile, prevent complete collapse and save lives. The extent of damage in a ductile building is of no significance in the event of a severe earthquake. Therefore, there is no need to modify any design provision as they are correct and well accepted all over the world.

Reply

Objective of ductile detailing is to delay the failure in structure by increasing the ductility so that necessary preventive measures can be taken to reduce loss of life. The total energy or capacity of the structure depends on three parameters stiffness, strength and ductility. By increasing the deformation capacity and decreasing the stiffness and strength will not improve the capacity of structure significantly and the extent of damage will be comparatively more. Damage from ductile detailing is expected to be less than normal detailing, which can be achieved by keeping initial stiffness and strength equal to normal detailed building i.e., by keeping same or increased member size in both cases. The provisions to satisfy above conditions are not mentioned in current design codes.

A normal detailed building is expected to exhibit brittle failure and collapse much earlier. Why your results are not showing this trend is not understood?

Reply

Same as 1(b).

Lastly, what is the secret behind Model 1 designed only for gravity loads but exhibiting a displacement ductility of 25.6 and R_μ = 7.0 (Table 8 and Figure 6(a)) – the best performance among all the nine models including special ductile frames?

Reply

Yes, from the figure 6 the displacement capacity of building designed for gravity loads is high. At the same time building shows extensive amount of damage compared to buildings designed for seismic zones because performance of the building depends on stiffness, strength & ductility and not displacement capacity alone (Table 11).

Queries raised by

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Replies by

Swajit S. Goud (PhD Scholar) and **Dr. R. Pradeep Kumar**, Head, Earthquake Engineering Research Centre, International Institute of Information Technology, Hyderabad.