Earthquake- resistant structures and IS 456 : 2000

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The recent earthquake in Gujarat has added to the growing concern and challenges to civil and structural engineers to design and construct safe structures, able to withstand earthquake forces. Apart from high standards of construction that are required for these structures, by use of appropriate specifications, good quality materials coupled with strict supervision, the other important aspect is the application of right standards for the design of earthquake-resistant structures. The recent publication of IS 456 : 2000, which is the key code for the design of all reinforced concrete (RC) structures, has added new dimensions to the present scenario, and its relevance in designing earthquake-resistant structures is to be seen in true perspective[1]. The following observations are made from the point of view of a structural design engineer.

As in the earlier 1978 version of IS 456 clause 19.4 under the heading 'Loads and forces', refers to IS 1893 : 1984 for the calculation of earthquake forces[2]. Further, in clause 26.1.2 under the heading 'Requirements governing reinforcement and detailing', the IS 456:2000 recommends the use of IS 13920 : 1993 and IS 4326 : 1993 for detailing of earthquake-resistant constructions[3,4]. Besides, there is *Table* 18 for the partial safety factors for the earthquake effects, to be used in the limit state method, and a clause for 33.33 percent increase in permissible stresses in the working-stress method. Apart from these limited references and guidelines, IS 456 : 2000 has not dwelled much on the earthquake-resistant structures.

In IS 1893, there is a map of India showing five seismic zones, and also a list giving the names of important cities and towns of India with their seismic zone number. The IS 13920 mentions under the heading 'Scope' that the provisions of this code shall be adopted in all RC structures which satisfy one of the following four conditions.

- The structure is located in seismic zone IV or V
- The structure is located in seismic zone III and has the importance factor (I) greater than 1.0
- The structure is located in seismic zone III and is an industrial structure
- The structure is located in seismic zone III and is more than 5-storey high

By referring to the list of important cities and towns of India given in IS 1893 : 1984, it is noticed that nearly 70 percent of these fall under the seismic zones of III and above, which include big capital cities like Kolkata, Mumbai, Delhi, Ahmedabad, Chandigarh, etc. The exceptions among the capital cities, which do not fall under this category are Bangalore, Chennai, Hyderabad , Jaipur and Bhopal. This indicates a broad spectrum of structures in the country that fall under the category that need to be designed and detailed as earthquake-resistant, as per IS 13920, and there are several thousands of these structures in the capital cities alone located in seismic zone III and above. When this requirement is of such a large magnitude, IS 456 : 2000 cannot ignore the importance of special detailing for these structures, and refers to IS 13920 by just one clause in the code. Instead, the clause 26.1.2 of IS 456 : 2000 should have listed out the four categories of structures given in IS 13920 for this purpose.

When nearly 70 percent of important cities fall under seismic zone III and above, IS 456: 2000 cannot ignore the importance of special detailing.

In order to assess the importance of reinforcement detailing for earthquake-resistant structures, it is necessary to see some of the important clauses of IS 13920 governing it but which differ from IS 456. For flexural members, like beams and lightly loaded columns (that is when ultimate axial stress in concrete is less than 0.1 x characteristic compressive strength of concrete, f_{ck}), the spacing of stirrups shall not exceed *d/4* or 100 mm minimum for a distance of *2d* from supports, and *d/2* for the remaining portion, where *d* is the effective depth of beam. This requirement is very much at variance with the minimum spacing of *0.75d* as per IS 456.

As per IS 13920, lap splices in flexural members are not to be provided:

- within a joint,
- within a distance of *2d* from the joint face, and
- within a quarter length of the member.

Not more than 50 percent of the bars are to be spliced at one location. These requirements on lapping arrangement of bars would involve careful preparation of detailed reinforcement drawings.

The details shown in *Fig* 1 for the anchorage of beam bars in an external joint is too much to be desired, as it is very much ineffective in cases of beams with large diameter bars to be anchored in to a column of smaller depth, for reasons given below. In *Fig* 1 of the code, $L_d + d_b$ located both at top and bottom of beam, are shown with a 90^0 bend. In practice, many engineers provide the required development length by just adding horizontal dimension from the inner face of column and vertical downward/upward dimension of the bar near the outer face, without considering the limitation of bearing stress at inner bends of bars as per clause 26.2.2.5 of IS 456 : 2000. It is observed that in the case of small size columns with large diameter beam bars, the standard radius of bend in bar equal to 2 x ϕ diameter for mild steel bars or 4 x ϕ diameter for high-yield strength deformed (HYSD) bars, usually provided as per IS 2502, would not be adequate for the purpose. A larger radius

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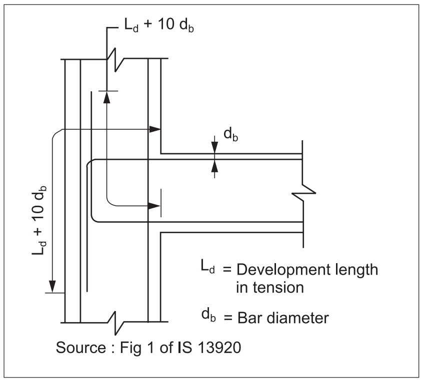

Fig 1 Anchorage of beam bars in an external joint

of bend in the bar would be required in order that the bearing stress in concrete at the bend is within the permissible limit. A method to calculate the radius of bend in bar by working stress method has been incorporated in IS 11682 : 1985 for criteria for design of RC staging for overhead tanks[5]. With large diameter bars, the required radius of bend would be too large, and impractical to provide.

One alternative method to the above details is to provide a cross bar, at least of the same diameter as the main bar, at the corner of bend in bar so that bearing stress in concrete is distributed over a larger area[6]. In cases where a cross beam is provided at the joint, that is normal to the plane considered, the corner bars in the cross beam can be so located that these are at the corners of the bends of the main beam. The more stringent requirement on the above anchor detailing comes from the New Zealand practice where the bar diameter in beams is restricted to 12 x column depth / f_y, where f_y is the yield stress of steel bar[7].

The requirements of IS 13920 on detailing of heavily loaded columns (when ultimate axial stress in concrete is more than 0.1 x f_{ck}), is more stringent as compared to those of IS 456 : 2000. Lapping of vertical bars is to be done in the central half of the member length only, and not very close to the joints. Only 50 percent of the bars are to be spliced at one location. All this means, in most cases, each bar will be a storey high, and 50 per cent of bars from foundations will be 1.5 storeys high, which could pose the problem of keeping the bars in position during construction.

As per IS 13920, the links in columns on either side of the joint are to be confined with closely spaced links for a length of:

- larger lateral dimension of the column,
- 1/6 of clear height of column, and
- 450 mm.

The spacing of the links is limited to ¼ of minimum column dimension, but need not be less than 75 mm nor more than 100 mm. Besides, clause 7.4.8 of IS : 13920 gives an equation to calculate the bar area of links in the confined location, which results in larger diameter link bars and use of HYSD bars for links. It is noted that smaller the size of columns, the link bar diameter will be larger, and in some cases it even results in 12 mm diameter HYSD bars for links. For locations, other than the confined areas, the spacing of links is limited to ½ of minimum column dimension. At lapping location of vertical bars, the spacing of links is not to exceed 150 mm. However, the spacing of cross ties in a column can be 300 mm which is more than 150 mm specified in IS 456 : 2000. All these requirements of IS 13920 on column links are provided to avoid sudden failure of the concrete when it reaches its compressive strength. Concrete can be made to act in a ductile manner by providing closely spaced links in the confined zone around the joints. These requirements are completely different from those given IS 456 : 2000, where the links are provided to prevent buckling of vertical bars under compressive load.

It would be appropriate to include all the special detailing requirements of IS 13920 in IS 456

From the aforesaid details, it is seen that the requirements of reinforcement detailing in earthquake-resistant structures, irrespective of their design seismic coefficient, in regard to spacing of stirrups in beams and links in columns, and lapping locations in both beams and columns are more stringent and significantly different as compared to those of IS 456 : 2000. As mentioned earlier, when several important structures, in as much as about 70 percent of the cities and towns in India, are to be detailed as earthquake-resistant structures, all the special detailing requirements specified in IS 13920 need to be included in IS 456 : 2000. This would also avoid the possibility of ignorance on the part of any structural designer about the special requirements of IS 13920.

Having said all about the requirements of IS 13920, one must say that reinforcement detailing as per these requirements is by no means an easy task. Firstly, everyone at site will blame the structural design engineer for providing too many closely spaced links and stirrups, and long bars for columns. If the engineer's service is provided for a builder, it would be most unlikely that he/she will get another assignment from the builder in future for this reason. The current practice of showing reinforcement details for beams and columns in a tabular form by some consultants, will not work if the details are in accordance IS 13920. The drawings have to be total with details of each and every bar shown in elevations and sections of beams and columns, with bar bending schedule. The site will have to strictly adhere to the detail drawings, and the lapping of bars have to be provided only at locations shown on the drawing, without leaving any option to the site engineer to deviate otherwise.

The requirements of IS 13920 for structures in zones III and above as mentioned earlier, are in effect since November 1993. How many of these structures in a big city like Delhi which is in seismic zone IV, and structures of more than five storeys high in the cities of seismic zone III, like Mumbai, Kolkata, Ahmedabad, etc have adhered to the detailing requirements of IS 13920. A national survey among design engineers may indicate ignorance of these requirements by many. Are the municipal engineers aware of these requirements or a self-certification by the design engineer concerned is sufficient to shelve their responsibilities from the public? These are some of the ponderable questions that are often raised repeatedly. After the Gujarat earthquake, a few consultants and contractors in Mumbai claimed through the media that their structures have withstood the earthquake! It is a subject that nobody can be too complacent about, as it occurred about 600 km away from Mumbai.

The design and construction of earthquake-resistant structures require more stringent and concerted actions, both from structural engineers and contractors, in terms of detailed design drawings, quality control in construction at all levels and supervision of work. When reinforcement is as closely spaced as 75 mm or 100 mm at the joints, concreting of these sections would require extra care in design of concrete mix and in compaction so that honey-combing does not occur at these locations. If the workmanship is bad, such structures will not be durable, and will deteriorate even before an earthquake strikes. IS 456 : 2000 has an important role to play in this matter, and it cannot just pass on this important aspect of construction by merely referring to another code.

References

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