Discussion Forum

Seismic retrofitting of RC shaft support of elevated tanks

I read with interest the technical paper titled "Seismic retrofitting of RC shaft support of elevated tanks" by Durgesh C. Rai, published in the November 2003 issue of the Journal[1]. I would like to congratulate the author for bringing out some important issues on the design aspects of elevated tanks, supported on circular shafts of reinforced concrete (RC), for seismic loads. However, I would like to discuss below some of the issues raised in the paper, particularly on the assessment of seismic loads on the shaft and on their sizing and design.

The paper deals in detail about the design and retrofitting aspects of a 10-to-12 year old water tank supported on a circular RC shaft in Jabalpur city, which was damaged due to earthquake that occurred on May 22, 1997. The paper concludes that the seismic forces calculated as per IS 1893: 1984 are too small for elevated tanks as compared to those prescribed by advanced standards of other countries, and on the non-ductile behaviour of thin-walled circular shaft sections. On these matters, I have the following observations to make.

First, the paper discusses the merit of using two-mass model approach for the seismic analysis, instead of one-mass model approach as recommended in IS 1893: 1984, particularly for those tank containers having height to radius ratio of less than 4. As mentioned in the paper, for the Jabalpur tank which has a low height to radius ratio of only about 0.23, the seismic shears and moments with two-mass model approach are only 56 percent and 74 percent of those calculated as per one-mass model approach. These discrepancies will however reduce as the ratio of height to radius of tank container approaches 4. This means that the values of seismic forces obtained as per IS 1893: 1984 are on the conservative side, and are not realistic for tanks with shallow containers. This is not a serious matter as far as safety is concerned, and in a way it helps in covering up other deficiency of the Indian code which is discussed later. Nevertheless, the Indian code needs to be modified to two-mass model approach as suggested in the paper.

Further, the paper observes that the design spectrum curves given in IS 1893: 1984 are applicable only for building systems, such as moment-resisting frame, and not for non-building systems, such as shaft supported elevated tanks. For short natural- period of vibrations, such as for the Jabalpur tank, spectral acceleration for non-building systems can be more than double of the spectral acceleration for building system, and the corresponding design seismic coefficient can be more than 3 to 5 times, depending on the value of other different parameters one chooses. For the Jabalpur tank, the author considers a spectral acceleration of 0.43 *g* based on the Newmark-Hall spectra shown in *Fig* 7(b) of the paper, instead of 0.2 *g* as per IS 1893: 1984, under the impulsive mode, by which the design seismic coefficient as per the paper works to 0.562 (= 8.15 MN/14.5 MN). But, as per IS 1893:1984, design seismic coefficient is only 0.06 by considering importance factor $I = 1.5$, soil-foundation factor $\beta = 1.0$, seismic zone factor for Jabalpur city $Fo = 0.2$, and acceleration coefficient Sa/g for natural period of 0.19 s (as per paper) and 5 percent damping = 0.2. The value of seismic coefficient obtained by alternative seismic-coefficient method of the code is also same. Even by the latest Indian seismic code IS 1893 (Part 1): 2002, the design seismic coefficient for the tank is only 0.1, considering zone factor $Z = 0.16$, importance factor $I = 1.5$, $Sa/g = 2.5$, and response reduction factor $R = 3$, as applicable for ordinary RC shear walls without ductile detailing.

The seismic moment at base level as per the paper is 203.4 MN.m by Housner's method and 218.8 MN.m by Malhotra *et al's* method, which are very high as compared to the seismic moment values of 46.18 MN.m and 77 MN.m obtained as per IS 1893: 1984 and 2002, respectively. All this means that both IS 1893: 1984 and the present IS 1893 (Part 1): 2002 appear to be outdated in their design spectra values for elevated water tanks on shafts, as compared to those given by Newmark-Hall and International code IBC 2000, both referred in the paper. In fact, the Newmark-Hall spectra was known in 1982, that is even before the publication of IS 1893 in 1984. This is a serious matter as water tanks designed as per IS codes in high seismic zones seem to be grossly under-designed at present for lesser seismic forces which make some of these tanks unsafe against earthquake. I hope that this deficiency in the present spectra values will be amended as necessary in Part 2 of IS 1893 for 'Liquid retaining tanks – Elevated and ground supported' at the earliest, which is yet to be published by the Bureau of Indian Standards.

On the second issue, which is on the sizing and design aspects of the RC circular shafts, there appears to be a gross error on the sizing of the shaft for the Jabalpur tank. For a tank shaft having a mean diameter of 17.4 m, 150 mm thickness seems to be very much inadequate. The IS code IS 11682: 1985 for RC staging of overhead water tanks, which is also referred in the paper, gives guideline on the minimum thickness of shafts. It is with a simple empirical equation for shafts greater than 6 m internal diameter, which is 150 + (Dci – 6000)/120, where Dci is the internal diameter of the shaft in mm. In fact, this equation in IS 11682 has been taken from IS 4998: 1975 and ACI 307-69 for RC circular chimneys. Structural designers who are familiar with design of RC chimneys, apply the above equation while designing the tank shafts and similar annular sections such as RC shafts of TV towers, etc, as a matter of routine. For the Jabalpur tank, the minimum thickness of shaft as per this equation works to 245 mm. Hence, there is an inadequacy in the shaft thickness of Jabalpur tank.

For the design of tank shafts, IS 4998: 1975 seems to be the only reference among Indian codes, which gives only working stress method at present for the design of circular sections. However, for limit-state method of design of circular shafts, there are enough literature available, such as the technical paper by Prof P.S. Rao and Menon, published in February 1995 issue of the Journal[2], and international chimney codes ACI 307-98, CICIND and German DIN 1056 which also consider the stiffening effect of concrete and second order moments for taller shafts. IS 4998: 1975 specifies permissible stresses for concrete and steel, and also gives design equations for combination of axial load, bending moment and temperature, etc., for annular sections with and without openings. The permissible stresses in both concrete and steel as per IS 4998: 1975 are lower those specified in IS 456: 2000 for working stress method.

If the shaft of Jabalpur tank is designed by working stress method as per IS 4998: 1975, the following observations are made. Considering an axial load of 32.3 MN and a seismic bending moment of 218.8 MN.m at base level as per *Table* 1 of the paper, for circular section of 150 mm thickness with a door opening of 0.9 m wide, using M 20 grade concrete and HYSD bars, the percentage of vertical steel required at each face of shaft will be 1.84 percent, which is very much higher than 0.11 percent actually provided as per the paper. Hence, the shaft is very much under-designed. But, if the design seismic moment is considered as 77 MN.m as per IS 1893: 2002, the vertical steel of 0.11 percent actually provided at each face is adequate. It is interesting to note that 150 mm thick shaft with 0.11 percent steel at each face can withstood safely a seismic moment of 130 MN.m and 32.3 MN axial load. If the shaft thickness of the Jabalpur tank had been 245 mm minimum as per IS 4998 and IS 11682, it would have safely withstood the design seismic values of *Table* 1 mentioned in the paper, including the additional weight and seismic moment due to increased thickness, with nominal vertical steel of 0.125 percent only at each face of shaft. In the last three cases, the whole shaft section is under flexural-compression only, which governs the design.

From the above it can be concluded that the shaft thickness of 150 mm for Jabalpur tank would have been just adequate if the seismic moment on the shaft had been as per IS 1893:1984 or even IS 1893 (Part 1): 2002. The distress of the Jabalpur tank shaft due to the 1997 earthquake can be attributed to providing very thin shaft of 150 mm thickness to withstand the high seismic loads cited in the paper. If the shaft had been correctly sized to 245 mm thickness as per the guidelines of IS 11682: 1985 and IS 4998: 1975, the tank shaft would have withstood those high seismic moment, with only nominal vertical steel at each face.

Briefly on ductile detailing, with the proper sizing of shaft, it is found in practice that the axial concrete stress and the percentage of reinforcement in shaft is invariably on the low side only. It is also noticed in large shafts, as in the above analysis, compressive stress in concrete only governs the design with proper sizing. Hence, appreciable ductility can be achieved if one follows the code on sizing. It is also normal practice in chimney construction to provide staggered laps in vertical bars in groups of three, and also in circumferential bars. Designers for water tanks can also adopt similar details. Several shaft-supported tanks, which have failed in the earthquakes of Bhuj and Jabalpur, seem to be due to non-compliance of the codes in sizing and reinforcing of the shaft. This particular aspect should allay the fears of some government and municipal agencies in constructing shaft supported tanks in high seismic zones in future. In fact, circular shaft sections are better equipped structurally to withstand seismic forces in any direction, besides these are easy and quick to construct, particularly with slip-form method. On the contrary, tanks supported on building frames comprising usually square or rectangular shaped columns and beams, are more complicated to design for bi-axial seismic moments and shears, and in deciding effective length of columns, etc., in addition to proper detailing for ductility and requiring high-quality construction, particularly at column-beam joints.

Lastly, on retrofitting method adopted for the Jabalpur tank, it is noted that new concrete jacket around the tank shaft is added by roughening the outer surface of the existing shaft. This method alone may be insufficient to provide the required composite action between the old and new concrete. Perhaps, an additional application of coat of a building chemical on the roughened surface to act as a bonding agent, combined with dowel bars between the old and new shaft are required to ensure full transfer of shear loads at the inter-face.

I trust that the readers of the Journal will find the above observations useful.

— Mr N. Prabhakar
Structural Consultant
Mumbai

The author replies:

I appreciate the interest taken, and the careful study by the discusser. The reply to major points appearing in the discussion is given below.

(i) The author concurs that design forces for elevated water tanks need to be revised upward urgently as

Indian standards specify forces which are too low compared to other international codes. For a detailed comparison of design forces among various codes, readers are referred to a review document by Jaiswal, *et al*[3]. It is also suggested there that response reduction factor for shaft supported elevated tanks should be 1.5, because thin shells of shafts are not ductile and devoid of advantages of redundancy of load paths.

(ii) The discusser is correct in pointing out that the Jabalpur tank was provided with a shaft shell thinner than required by IS : 11682. A thicker shell would have added to the strength and the tank may have escaped damage in the 1997 Jabalpur earthquake. However, the minimum thickness requirement shall not be taken as a statement on strength demands.

(iii) A large amount of ductility can not be achieved with thin shells of the shaft staging[4,5]. On the contrary, an appreciable level of ductility is possible with framed staging of the framing members and joints are properly detailed. Further, alternative load paths available in framed staging add to the redundancy of the load-resisting system, which is non-existent for the shaft type staging.

(iv) For thin shell of Jabalpur tank shaft, interfacial flexure shear between new and old concrete are negligibly small and roughening the existing surface is adequate. However, such interfacial shear was significant in pile cap and dowel bars were provided to help transfer the shear forces.

References

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— Dr Durgesh C. Rai
Assistant Professor
Indian Institute of Technology Kanpur, Kanpur

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