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Stability Analysis of Monument: A Case Study–Safdarjung Tomb

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Abstract Present study deals with the stability analysis of an existing historical monument “Safdarjung Tomb” under Seismic Load. The tomb is situated at New Delhi, India. The building is classified as protected monument by the Archaeological Survey of India (ASI). This is a ground plus two storey masonry structure with a central dome.

The basic seismic parameters have been evaluated using Bureau of Indian Standards (BIS) Codal method. Distribution of lateral forces is carried out to individual piers and walls using Rigidity Approach.

The seismic performance of the building is studied under the gravity and earthquake loads. The building is modeled as a two-degree-of-freedom shear-beam system. The piers, which are located parallel to the direction of earthquake shaking are assumed to provide spring action. The mass of the walls and slabs are lumped at the storey levels. The lumped masses are assumed to be connected to each other through massless springs. The degree of each mass in horizontal direction is considered, neglecting the vertical translational and rotational degrees of freedom. Stiffness of the walls parallel to longitudinal and transverse directions of the building has been computed separately which was used for computation of lateral forces in each direction. The forces so evaluated are used in pier analysis to evaluate stress induced in various elements.

The majority of the structural elements were found safe and the overall structure is stable. The stresses due to shear and bending are within permissible limit.

Keywords: Masonry, pier Analysis, rigidity

Introduction

Masonry construction was widely used in the ancient period because of use of locally available material, need of less skilled labor, less engineering intervention etc. However, there are some disadvantages for this type of construction, particularly, when it is built in seismic environment. The seismic resistance capacity of masonry construction is relatively low in comparison to engineered construction. In India, masonry construction are generally made by using locally available material like stone, brick, timber, mud etc. and are constructed in a traditional manner with or without earthquake resistance features. Therefore, this type of construction is treated as non-engineered construction and most of the causalities occur due to the collapse of these constructions in earthquake. The present study is an attempt in this direction to study the stability of an existing monument “Safdarjung Tomb” New Delhi. This is an unreinforced Stone Masonry Historical Building. Safdarjung's tomb situated at New Delhi has been considered as a case study built in 1753-1754. The building is situated in the high seismic zone IV. The observation on the building shows cracks and sign of distress at many locations due to weather, load effects and foundation settlement which makes the basis of the study. After Gujarat Earthquake of January 26, 2001, it was observed that few crakes appeared in the building. The lateral load resistance to the building is provided by load bearing unreinforced masonry walls. A detailed survey was carried out and the various inputs were prepared to study the performance of the building studied under the gravity and earthquake loads.

Methodology

The monumental building is modeled as two-degree-of-freedom shear-beam system. The piers, which are located parallel to the direction of earthquake shaking are assumed to provide spring action. The mass of the walls and slabs are assumed lumped at the storey levels. It is assumed that the lumped masses are connected to each other through mass-less springs. The degree of each mass as horizontal translation is considered, neglecting the vertical translational and rotational degrees of freedom. So modeled brick building system leads to a simplified mathematical model.

Following are the major steps for the lateral load analysis of masonry buildings (Agarwal and Shrikhande 2006, Drysdale and Hamid 1994):

Step 1: Determination of lateral loads

The design base shear is computed as a whole, and then be distributed along the height of the building. The design lateral force obtained at each floor level is then distributed to individual lateral load resisting element depending upon floor diaphragm action. Following are the steps for determining the lateral forces.

Design seismic base shear:

The design seismic base shear force, V_B

$$V_B = A_h W \quad (1)$$

W = seismic weight of the building, A_h *= The design horizontal seismic coefficient*

$$A_h = \frac{Z * I * S_a}{2 * R * g} \quad (2)$$

Z = Zone factor, table 2 of IS 1893 (Part 1): 2002

I/R = Ratio of importance factor and response reduction factor (Table 6 and 7 of IS 1893 Part 1:2002)

S_a/g*=Average response acceleration coefficient based on soil type, on natural period and damping of the structure.*

Time period of building $Ta = \frac{0.09h}{\sqrt{d}}$ (3)

h = height of building, (m)

d = base dimension of the building at plinth level, along considered direction of the lateral force,(m)

Vertical distribution of base shear to different floor levels

Lateral load at ith floor level (Q_i)

$$Qi = V_B \frac{Wihi^2}{\sum_{i=1}^{n} Wihi^2} \quad (4)$$

Q_i =design lateral force at floor i, W_i =seismic weight of floors i,

h_i = height of floor i , measured from base, n = number of stories in the building

Step 2: Determination of rigidity of shear wall

Pier analysis

Deflection of Cantilever pier (Δc)

$$\Delta c = \Delta m + \Delta v = \frac{Ph^3}{3E_m I} + \frac{1.2Ph}{AG_m} \quad (5), \qquad \Delta c = \frac{P}{E_m t}\left[4\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] \quad (6)$$

Rigidity of cantilever pier $R_c = 1/\Delta_c$

Deflection of Fixed pier (Δf)

For a wall/pier fixed at top and the bottom, the deflection from a force, P

$$\Delta f = \Delta m + \Delta v = \frac{Ph^3}{12E_m I} + \frac{1.2Ph}{AG_m} \quad (7), \qquad \Delta f = \frac{P}{E_m t}\left[\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] \quad (8)$$

Rigidity of fixed pier, $R_f = 1/\Delta_f$

Δ_m = deflection due to flexure bending, Δv = deflection due to shear, P = lateral force on pier, h = height of pier, A = cross section of pier, E_m = modulus of elasticity in compression , G_m = modulus of elasticity in shear

For masonry, $G_m = 0.4E_m$

Method for calculating the rigidity of wall with opening

(i) Calculate the deflection of the solid wall as a cantilever, $\Delta_{solid(c)}$ (for one or two storey building)
(ii) Calculate the cantilever deflection of an interior strip, having a height equal to that of the highest opening, is calculated and subtracted from the solid wall deflection. This step removes the entire portion of the wall containing all the openings.
(iii) Calculate the deflections of all the piers as fixed within that interior strip being determine by their own individual rigidities ($\Delta_{piers(f)}$)
(iv) Add deflections of piers to the modified wall deflection to arrive at the total deflection of the actual walls with openings (Δ_{total})
(v) The reciprocal of this value becomes the relative rigidity of the wall [$R = 1/\Delta_{total}$]

The stiffness of the walls parallel to longitudinal (L-direction) and transverse (T-direction) directions of the building has been computed separately. This has been done based on the assumption that the shear walls located parallel to the transverse direction of the building would resist any expected earthquake ground motion occurring in this direction. Similarly, walls located in the longitudinal direction of the building would be anticipated to resist any seismic force in the longitudinal direction of the building. Finally, relative stiffness ratio of each pier of the shear walls parallel to L- and T- directions for each storey is determined to assess their share in resisting the seismic force.

Step 3: Determination of direct shear forces and torsional shear forces

Direct shear forces

In case of rigid diaphragm it is assumed that the walls are tied together with the diaphragm, the lateral force (P) will be distributed to the walls in proportion to their relative stiffness.

For any wall i^{th}, the relative stiffness k_i is given by,

$$Ri = \frac{k_i}{\sum k_1 + k_2 + k_3 + \dots\dots\dots + k_n} \tag{9}$$

Direct shear force on parallel walls $(V_D)_i = R_i P$ (10)

Torsional shear forces

Torsional moment, M_t, is induced that is equal to $P_y \times e_x$, where e_x equals the distance between the line of force (centre of mass) and the centre of rigidity. Even in symmetrical structure, where $e = 0$, a minimum eccentricity amounting to 5% of the building dimension is assumed which is called accidental eccentricity.

Centre of mass

$$\overline{X}_m = \frac{\left(\sum W_{Li} X_i + \sum W_{Tj} X_j + \sum W_{Ri} X_i\right)}{\left(\sum W_{Li} + \sum W_{Tj} + \sum W_{Ri}\right)} \tag{11}$$

$$\overline{Y}_m = \frac{\left(\sum W_{Li} Y_i + \sum W_{Tj} Y_j + \sum W_{Rj} Y_j\right)}{\left(\sum W_{Li} + \sum W_{Tj} + \sum W_{Rj}\right)} \tag{12}$$

W_{Li} = weight of longitudinal walls, W_{Tj} = weight of transverse walls, W_{Ri} = weight of transverse walls

X_i, Y_i = distance between C.G of longitudinal wall and reference point.

X_j, Y_j = distance between C.G of transverse wall and reference point.

Centre of rigidity $(\overline{X}r, \overline{Y}r)$

$$\overline{X}_r = \frac{\sum R_T x}{\sum R_T} \quad , \qquad \overline{Y}_r = \frac{\sum R_L y}{\sum R_L} \tag{13}$$

Torsional eccentricity,

$$e_x = \overline{X}_m - \overline{X}_r \ , \qquad e_y = \overline{Y}_m - \overline{Y}_r \tag{14}$$

R_L = rigidity of longitudinal walls, *R_T = rigidity of transverse walls*

Step: 4 Determination of increase in axial load due to overturning moment

Torsional forces in L- walls and T- walls = $\frac{R_x d_y}{\sum R_x d_y^2} V_x e_y$ and $= \frac{R_y d_x}{\sum R_y d_x^2} V_y e_x$ (15)

dx, dy = Distance of considered wall from centre of rigidity.

Step 5: Walls subjected to out-of-plane bending

Stress due to combined axial compression and bending (F_m) $F_m = P/A + M/S$ (16)

Fm = limiting stresses for combined axial compression and bending

A = area of section, S = section modulus,P = Axial Compression,M = Bending Moment

The unity equation $\frac{f_a}{F_a} + \frac{f_b}{F_b} \le 1.33$ (17)

f_a, f_b = compressive stresses due to applied axial load and bending,

F_a, F_b = allowable axial and bending compressive stresses

$$f_a = \frac{P_{total}(P_d + P_l + P_{ovt})}{width\ of\ Pier\ (d) * t} \quad (18) \qquad f_b = \frac{M}{td^2/6} \quad (19)$$

F_a = permissible compressive stress, F_b = permissible bending stress

Equations 16 and 17 are used for describing linear behavior of section. For masonry, the effects of tensile cracking, non-linear stress- strain behavior of section, the equation is conservative (Agarwal and Shrikhande 2006).

Seismic Response of the Monumental Building

Determination of the structural properties of the building elements (walls) and the selection of the earthquake input are the most critical parameters in the seismic response evaluation. Seismic weight of the building has been determined employing the appropriate material and mechanical properties. The detailed seismic analysis of the building has been completed using IS 1893 (Part I) (2002).

The seismic storey shears resulting with torsional moment are obtained (where the condition of no-torsion is not satisfied, the distance between the centres of mass and rigidity gives the eccentricity of the earthquake force in plan of the structure). The torsional moment is then equal to the seismic force times the eccentricity and the resulting shears in the walls are computed. The shear force in each shear wall of the storey is then determined by distributing the storey shear among the shear walls in proportion to their stiffness.

Basic Data For Seismic Force Determination (Amaan et al. 2009)

Type of Building = Symmetric Heritage Building, Number of Story = G + 2
Material of Building = Sand Stone, Unit weight of material = 22kN/m^3
Modulus of Elasticity = 30kN/m^2, Design Compressive Strength =2.5N/mm^2
Soil type = Hard Soil, Height of Building (h) = 21.65m
Base Dimension (d) = 58.63 m, Seismic Zone = IV
Zone factor (Z) = 0.24, Importance factor (I) = 1.5
Response Reduction Factor (R) = 1.5, Damping factor (D) = 10%
Live load on 1st Floor= 5kN/m^2, Live load on 2nd Floor and roof =3kN/m^2

Permissible Stresses for Design

The permissible stresses for materials used in the building are:
F_a (compressive) = 2500 kN/m^2, F_b (bending) = 3125 kN/m^2 and f_s (shear) = 200 kN/m^2
Since, the building is very old, it is estimated that the above permissible stresses may be reduced to fifty percent to evaluate the present overall seismic strength of the building elements. (NICEE 2004)

1) Seismic Force Determination (Amaan et al. 2009)

Weight of building, base shear, distribution of lateral force at floor level and eccentricities (Including 5% accidental eccentricity) are given in Table 1 to Table 7

Table 1: Weight Of The Building

Details	*Weight* (kN)	*Details*	*Weight* (kN)
Ground Floor Longitudinal Walls	66478	Second Floor Transverse Walls	15309
Ground Floor Transverse Walls	32145	Second Floor Slab	14565
Ground Floor First Slab	57475	Longitudinal Dome Base Walls	2102
Ground Floor Second Slab	11382	Transverse Dome Base Walls	2062
First Floor Longitudinal Walls	15309	Dome	6108
First Floor Transverse Walls	15309	Live Load on GF	8593
First Floor Slab	14565	Live Load on FF	809
Second Floor Longitudinal Walls	15309	Live Load on SF	809
Total		278327	

Table 2: Base Shear

Details	*Symbols*	*Value*	*Unit*	*Equation. No.*
Time Period	T	0.25	sec	2
Avg. Responce Acc. Coeff. (10%)	Sa/g	2.0		
Design Hor. Seismic. Coeff.	A_h	0.24		1
Design Base Shear	V_B	66799	kN	3

Table 3: Vertical Distribution Of Lateral Force (Qi) and Storey Shear (Vi)

Level	*Height* (m)	W_i (kN)	$W_i.h_i^2$	Q_i (kN)	*Vi* (kN)
Level +21654	21.65	8190	3838666	11629.84	11629.84
Level +17619	17.62	32765	10172338	30818.69	42448.53
Level +10990	10.99	45992	5554939	16829.56	59278.09
Level +4182	4.18	142069	2482291	7520.49	66798.58
		TOTAL	22048234		

Table 4: Ground Floor Eccentricity

	Centre of Mass	*Centre of Rigidity*	*Eccentricity*		
			Static	*Accidental*	*Design*
	m	m	m	m	m
X	27	28	1	2.93	3.87
Y	27	28	1	2.93	3.94

Table 5: First Floor Eccentricity

	Centre of Mass	*Centre of Rigidity*	*Eccentricity*		
			Static	*Accidental*	*Design*
	m	m	m	m	m
X	12	14	1	1.29	2.29
Y	12	14	1	1.29	2.29

Table 6: Second Floor Eccentricity

	Centre of Mass	Centre of Rigidity	Eccentricity		
			Static	Accidental	Design
	m	m	m	m	m
X	12	14	1	1.29	2.29
Y	12	14	1	1.29	2.29

Table 7: Dome Eccentricity

	Centre of Mass	Centre of Rigidity	Eccentricity		
			Static	Accidental	Design
	m	m	m	m	m
X	7	7	0	0.65	0.65
Y	7	7	0	0.65	0.65

Determination of Stresses (Amaan et al. 2009)

Total Shear Force in the Walls

Using the following relationship, total shear force in the walls is determined as follows:

$S = S_W + S_T$, where

S = Total shear in longitudinal (L) and transverse (T) walls

S_W = Shear force in individual walls, S_T = Torsional shear in individual walls

(Only positive S_T will be added and negative S_T will be ignored)

Shear Stress

The average shear stress is computed employing the respective total shear force and the area resisting the shear for each wall piers. The permissible shear stress is denoted by f_s.

Bending Stress

The pier method of analysis has been employed to compute the bending stress. Shear force in each building element causes bending moment. The bending stress is work out knowing the section modulus of the wall pier.

Overturning Stress

The overturning moment on the building due to seismic force has been determined. Using the appropriate geometrical properties of the wall piers, the overturning stress is computed in the piers taking care of proper sign for the stresses.

Axial Stress

Axial stress in the wall piers is determined using the overturning stress and the stress due to the gravity loads shared by the individual wall piers.

Final Stress

The stresses in direct compression (f_a) and flexure (f_b) are algebraically combined to get the final stress in all the wall piers. Equation No. 17 gives the final check for the seismic safety of the wall piers.

Discussion of Results

Based on the analytical models of the identified existing building and its requisite data, the results of the analysis have been summarized in the Tables 1 to 131 elsewhere for all the wall piers situated in the longitudinal and transverse directions, for the unidirectional occurrence of earthquake ground shaking at a time (Amaan et al. 2009).

From the results of the study, it was found that majority of the structural elements were found safe under an earthquake attack in both the longitudinal and transverse directions.

Conclusions

The design forces, determined by considering direct and torsional forces due to lateral load, axial load and due to overturning in addition to live load and dead load are compared with permissible values and on the basis of the analysis and calculation results following conclusion are made:

I. The unity equation (equation 17) is satisfied, therefore the overall structure is stable, and no pier was found weak.
II. The stresses are within permissible limit.
III. The structure is safe both in shear and bending.
IV. From the visual inspection, the cracks occurred might be due to deep penetration of roots, disintegration of materials due to water seeping in some of the parts of the structure.
V. The Wall-Floor Area Ratio is high, this is also one reason for the stability of historical monuments.
VI. These cracks may lead to severe damage to the structure during an earthquake, hence repairing and retrofitting should be done.

References

[1] Agarwal, P K, and Shrikhande, M (2006). "Earthquake resistant Design of Structures." Printce Hall of India Pvt. Ltd. , New Delhi, 2006

[2] Ahmad, K M, and Qamaruddin, M (2006), " Seismic Evaluation of a Heritage Brick Masonry School Building," in *Proceedings of 7th International Masonry Conference*-London 2006

[3] Amaan et al. (2009). "Stability Analysis of Historical Monuments (A Case Study – Safderjung Tomb." B.Tech Dissertation submitted to Department of Civil Engineering, Jamia Millia Islamia, New Delhi.

[4] Brar, T S (2003). "Retrofitting of Heritage Structures – A Conservative Approach," in *Proceedings of Workshop on Retofitting of Structures*, Oct. 10-11, Roorkee PP 331-347

[5] Building Materials and Technology Promotion Council (BMTPC), (2006). Ministry of Housing and Urban Alleviation, Government of India, New Delhi.

[6] Danish, M, and Imran (2005). "Seismic Analysis of Masonry Building." B.Tech Dissertation submitted to Department of Civil Engineering, Jamia Millia Islamia, New Delhi.

[7] Drysdale, R G and Hamid, A A (1994). "Masonry Structures Behaviour and Design." Printce Hall Inc. , New Jeresy

[8] Earthquake resistant regulations (1992). "A World List - International Association of Earthquake Engineering".

[9] IS 13828: (1993). Indian Standard Code. "Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines." Bureau of Indian Standards, New Delhi.

[10] IS 13935 (1993). Indian Standard Code. "Repair and Seismic Strengthening of Buildings – Guidelines." Bureau of Indian Standards, New Delhi.

[11] IS 13935: Draft first revision June 2004. "Guidelines for Repair, Restoration, Condition Assessment and Seismic Strengthening of Buildings." (by A S Arya).

[12] IS: 1893 Part I: 2002 Indian Standard Code. "Criteria for Earthquake Resistant Design of Structures." Bureau of Indian Standards, New Delhi.

[13] Module 3 (2004). "Seismic Assessment and Retrofitting of Buildings," in *Proceeding of the Workshop on Capacity Building in Earthquake Engineering*, New Delhi, Published by office of the Divisional Commissioner Government of NCT of Delhi, Under Government of India – UNDP Disaster Risk Management Programme.

[14] NICEE, IIT-Kanpur (2004). "Guidelines for Earthquake Resistant Non-Engineered Construction" (Revised Edition of Basic Concept of Seismic Code, Volume 1 Part 2, 1980, International Association for Earthquake Engineering).

[15] Qamaruddin, M (2007). "Seismic Safety and Strengthening of Existing Buildings." Research Report funded by All India Council for Technical Education (AICTE Grant No. 1-51/CD/EF(041)/2003-2004 dated 8th December 2003), Department of Civil Engineering, Jamia Millia Islamia, New Delhi, March 2007.

[16] Qamaruddin, M, Ahmad, A, and Moin, K (2007). "Seismic Performance of A Heritage Brick Masonry School Building," in *National Conference GSEE-07*, Jamia Millia Islamia , New Delhi.