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# Base Isolation for Architectural Temples

**[Radhikesh P. Nanda]**

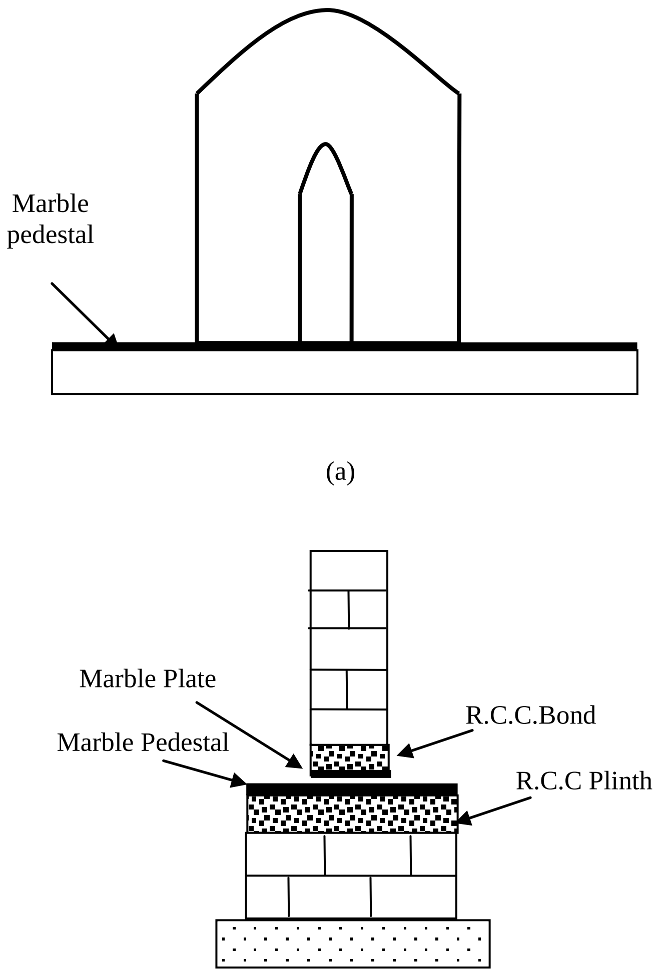
***Abstract*— The paper addresses earthquake protection for architectural masonry temples of India, which are supported over large marble pedestal. The concept of seismic isolation has been applied here to these temples by separating the super structure from the pedestal by a smooth friction layer in the form of marble/marble interface. The response of the base isolation system is estimated numerically by solving the governing equations of motion under earthquakes ground motion compatible with the 5% damping design spectrum of Indian standard code for earthquake resistant design corresponding to the level of maximum considered earthquake in the most vulnerable seismic zone. In comparison with the response of the fixed base structure, nearly 50% reduction in absolute response acceleration for the isolated temple building was observed at the roof level at the cost of 30 mm base sliding displacement, which is well within large marble pedestal and can be used as a base isolation technique for preserving low rise architectural temples which generally conceived to be the monuments and heritage structure in future.**

***Keywords*— Architectural temples, base isolation, earthquake protection, masonry, monuments.**

## I. Introduction

In December 2003, a devastating earthquake in Iran virtually leveled the historic heart of Bam – a 2000 years old citadel. Similar examples in different parts of the world - Mexico City earthquake in 1985, San Salvador Earthquake in 1986, Athens- Greeece, 1999. Beyond the obvious need to protect human life, one must also take the responsibility of protecting architectural temples as these structures are the dynamic linkage of contribution by each generation in the continuum of society. Most of the architectural temples are conceived to be the monuments in future. Once they are lost a part of history will be lost forever. Because of heavy mass and stiffness the seismic resistance capacities of these masonry temples are relatively low and have suffered maximum damage in earthquakes. To improve the seismic behaviour of these structures, the seismic base isolation by pure friction (P-F) sliding system was explored wherein a smooth sliding layer in the form of marble/marble interface (Figure 1) was introduced at pedestal level, on which the super structure simply rests and was free to slide except for friction resistance.

The basic concept is to decouple the structure from the damaging effect of horizontal shaking during earthquake by allowing sliding of super structure at pedestal top level. The use of base isolation technique as seismic protection system by providing a sliding interface at the plinth level to permit relative motion between the superstructure and the substructure has been studied earlier by Lou *et al*.[1], Nikolic-Brzev and Arya [2], Tehrani and Hasani [3], Qamruddin and Ahmad [4], Nanda et al. [5 & 6] and Ahmad *et al.* [7]. A low coefficient of friction at the sliding interface leads to reduced roof acceleration and base shears at the cost of increased base sliding displacement as the superstructure slides across pedestal during earthquake and therefore a usable range of friction coefficient has been recommended as (0.05, 0.15) [8].



(a)

(b)

Figure 1. Construction detail for frictional base-isolation system for architectural temples with (a)large marble pedestal and (b)wall section.

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Authors Name; Dr. Radhikesh P.Nanda, Dept. of Civil Engineering,
NIT Durgapur, Durgapur
India

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## II. Mathematical Modeling

A two-mass model as shown in Fig. 7 was used to describe the seismic behavior of a single story temple building with a sliding interface. The mass of the roof in addition to one half the mass of the wall is lumped at the roof ($M_t$) while the rest is lumped at the base with the mass of the bond beam ($M_b$). The base mass is assumed to rest on a plane with dry friction damping of coulomb type to permit sliding of the system. The rocking effect is assumed to be neglected.

Let the ground acceleration be denoted by $\ddot{x}_g$ ; $x_t$ and $x_b$ represent the relative displacement of top mass with respect to bottom mass and relative displacement of the bottom mass with respect to ground respectively; and $\theta\,(= M_t / M_b)$ be the mass ratio (MR). The natural frequency of the non-sliding system ($\omega_n$) is related to the stiffness ($K$) and the top mass as $\omega_n = \sqrt{K / M_t}$ , and $\xi\,(= C / 2\omega_n M_t)$ is the fraction of critical damping, where $C$ is the damping coefficient.

The governing differential equation for non-sliding condition can be obtained from equilibrium considerations as:

$$M_t(\ddot{x}_g + \ddot{x}_t) + C\dot{x}_t + Kx_t = 0 \qquad (1)$$

The above equation governing the dynamic response of the system to base excitation during non-sliding condition is exactly same as that for a fixed base system. The sliding of bottom mass begins when the sliding force overcomes the frictional resistance at the plinth level. The monument building now acts as two degree of freedom system and governing differential equation of motion of top mass can be derived from equilibrium considerations:

$$M_t(\ddot{x}_g + \ddot{x}_b + \ddot{x}_t) + C\dot{x}_t + Kx_t = 0 \qquad (2)$$

while the motion of the bottom mass may be described by:

$$M_b(\ddot{x}_g + \ddot{x}_b) - C\dot{x}_t - Kx_t + \mu(M_t + M_b)\mathrm{g}\ \mathrm{sgn}(\dot{x}_b) = 0 \quad (3)$$

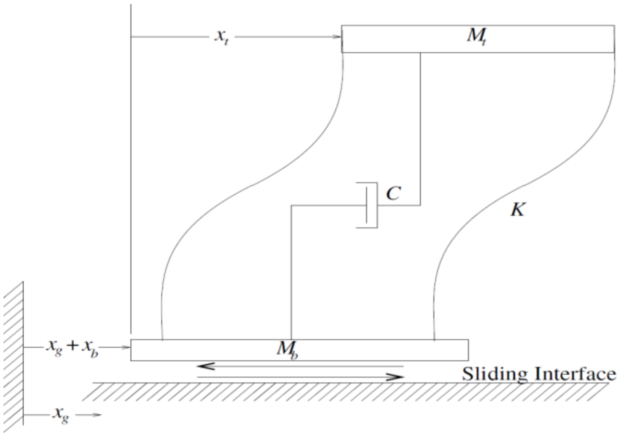

Figure 2. Mathematical model and free body diagram for non- sliding and sliding system.

where, $\mathrm{sgn}(x) = \begin{cases} 1, & x > 0 \\ -1, & x < 0 \end{cases}$ denotes the signum function.

The non-sliding condition prevails when the horizontal inertia force of bottom mass does not exceed the opposing friction force at plinth level, *i.e.*

$$\left| C\dot{x}_t + Kx_t - M_b(\ddot{x}_g + \ddot{x}_b) \right| < \mu(M_t + M_b)g \qquad (4)$$

These equations are solved by using Runge-Kutta 4th order solver in MATLAB-SIMULINK environment.

## III. Experimental Study

The dynamic characteristics of the pure-friction interface for seismic protection of masonry buildings were investigated via friction tests with large shear box unit. Specimens of 200 mm diameter and 50 mm height (Figure 3) were prepared in 1:1.5:3 concrete cast with smooth marble (green or white) on one side. The specimens were kept in lower and upper shear box to permit sliding along the smooth marble/marble interface. Static tests were conducted under controlled displacement (Figure 4). The ramp rate had been kept constant at 0.5 mm/s with ramp limit of 25 mm and the normal load was varied from 10 kN to 50 kN which correspond to load at plinth level for low rise temples. Load and displacement data were obtained from the load cell and displacement transducer embedded in the actuator system. From load displacement curve average value of the coefficient of friction was obtained to be 0.09.

Figure 3. Experimental set up for friction test with Shear Box(photographic view)

Figure 4. Samples for friction test.

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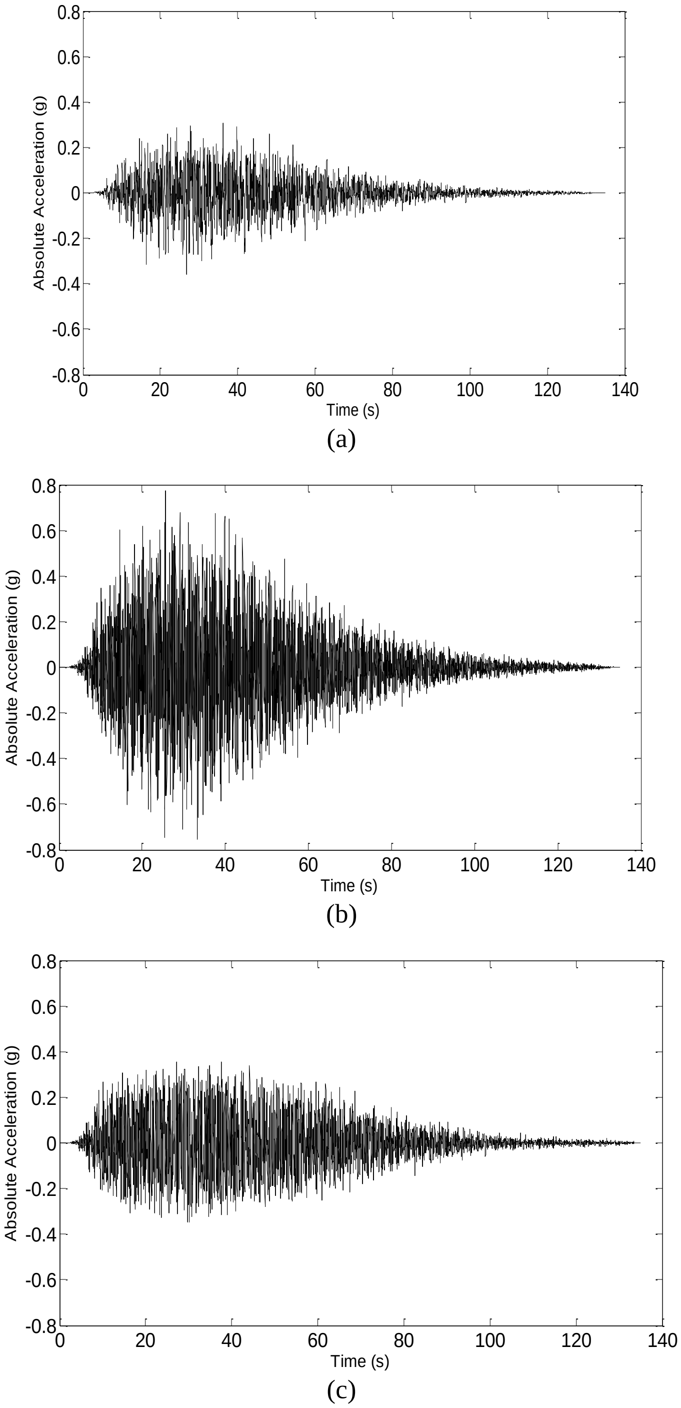
## IV. Analytical Study

The effect of the ground motion on the behaviour of friction isolation system is investigated analytically by using a synthetic accelerogram that is compatible with the design spectrum of Indian standard (IS 1893 (Part 1): 2002) [9] corresponding to the level of maximum considered earthquake in the most vulnerable seismic zone (PGA=0.36g).



(a)

(b)

(c)

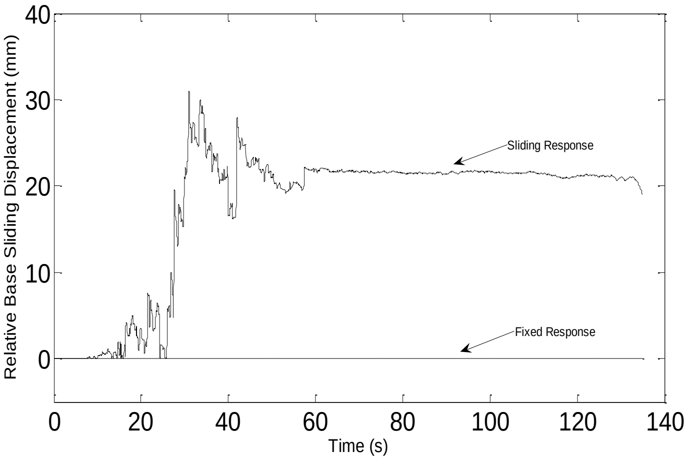


Figure 5 (a) Ground motion, (b) absolute acceleration response at roof level for fixed base, (c) absolute acceleration response at roof level for marble/marble sliding isolator, and (d) Relative sliding displacement at base.

Figure 5 (a) Represents the ground motion, while 5 (b) & (c) represents corresponding absolute acceleration response at roof level for fixed base and sliding single story building of mass ratio (MR) = 3, time period ($T_n$) = 0.1 sec and damping 5% critical respectively. In case of fixed building there is amplification in response in all cases. The peak absolute acceleration at roof level is 0.8g while 0.38g for sliding couples i.e. 50% reduction in roof acceleration. Figure 5 (d) Represents the relative base sliding response for fixed base and sliding single story building of mass ratio (MR) = 3,time period 0.1 sec and damping 5% critical. From relative displacement it is found that the maximum relative sliding displacement is within 30 mm which is well within the normal plinth projection.

## V. Conclusion

Attempt has been made to decouple the temple structure from the damaging effect earthquake by allowing sliding of super structure at pedestal top level. The response of the base isolation system is estimated numerically by solving the governing equations of motion under earthquakes ground motion compatible with the 5% damping design spectrum of Indian standard code for earthquake resistant design corresponding to the level of maximum considered earthquake in the most vulnerable seismic zone. In comparison with the response of the fixed base structure, nearly 50% reduction in absolute response acceleration for the isolated temple building was observed at the roof level at the cost of 30 mm base sliding displacement, which is well within large marble pedestal and can be used as a base isolation technique for preserving low rise architectural temples which generally conceived to be the monuments and heritage structure in future.

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About Author (s):

Most of the architectural temples are conceived to be the monuments in future. Once they are lost a part of history will be lost forever.

Dr. Radhikesh P. Nanda, presently working as associate Professor at NIT Durgapur, India. Member of IRED, ISET(India), FIE (India), ISTE, IRC.