

# **METHODOLOGY FOR STRENGTHENING AND REPAIR OF EARTHQUAKE DAMAGED MONUMENTS IN PAGAN - BURMA**

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## **SUMMARY**

For development of an adequate method of repair and strengthening of the monument structures, seismic studies and seismic hazard assessment as well as geophysical and soil investigations for definition of the local soil conditions, have been carried out. Based on the defined seismic design criteria, a methodology for repair and strengthening of this type of structures has been developed under the Project – UNSECO/UNDP project Burma 78/023.

## **1. INTRODUCTION**

The Pagan plateau, in the central part of Burma, is a world-wide known place for the high concentration of magnificent historic monuments from the distant past like temples and pagodas. Unfortunately, most of these have severely been damaged by natural disasters, including earthquakes.

The earthquake of 8th July 1975, with a magnitude of 6.8 destroyed or heavily damaged many monuments - temples and pagodas. On the basis of the study of the neotectonic and seismotectonic characteristics of the wider Pagan region (where earthquakes with magnitudes of up to 8 can be expected) and based on the methodology for probabilistic seismic hazard modeling, statistical analysis of earthquake data and selected attenuation relationship, the seismic hazard data are presented in terms of peak ground acceleration for average soil conditions.

## 2. DESCRIPTION OF TYPE OF STRUCTURES, BUILT-IN MATERIALS AND DYNAMIC PROPERTIES AND TYPE OF STRENGTHENING

The general conclusion is that the bricks are of a good quality, while the low load carrying capacity is due to the poor bearing capacity of mortar. From the experimental testing of the dynamic properties of 16 selected monuments applying the ambient vibration technique and the developed analytical models, it was determined that the elasticity modulus is within the range of  $M_{MI}$  (160-220) MPa, the shear modulus is  $G = (50-60)$  MPa and the damping ratio is  $c = (6-12\%)$ . The mode shape analysis, both experimental and analytical, pointed to shear type behaviour of the lower rigid parts and bending type of behaviour of the upper parts of the monuments. Basically, almost all the selected monuments that were subject of experimental testing of the dynamic characteristics show that the structures are rigid, with a natural period in the range of  $T_1 = (0.15-0.57)$  sec., which is mainly due to the geometry and size of the monuments. Based on the experimental measurements and the analytically obtained values of the selected monuments, a relationship for definition of the fundamental period of vibration has been established in order to be applied in design, repair and strengthening of the monuments.

The analysis of damaged monuments, particularly the selected representative monuments, taking into account their structural systems and characteristics of built-in materials points to possible failure mechanisms; (i) loss of integrity of the structural system due to low tensile capacity of masonry, occurrence of cracks at each storey level and separation of the massive walls from the rigid central pillars or cores and independent working of each element proportional to the mass and the natural stiffness which prevents the force distribution proportional to the mass; (ii) failure or damage to tall and slender elements (shikaras) and the secondary decorating elements (corner stupas) due to amplified effects and low bearing capacity, and (iii) shear failure of walls or the upper parts of the stupas due to the poor quality of mortar and shear force resistance. Taking into account the above described modes of failure, the material properties and the structural systems, the dynamic characteristics and the expected possible earthquakes, the following method of strengthening and repair of Pagan monuments has been proposed:

- (i) Preserving of the structural system integrity at each storey level by inserting of steel bracings for small and medium size temples and/or by construction of reinforced concrete belt courses around the structure and at each storey as defined by the free height of corridors and halls in the case of medium size temples, (Fig. 1).
- (ii) Strengthening of the upper slender parts of the monuments (shikaras) by inserting of horizontal R/C belt courses and injection, (Fig. 1).

Based on the performed studies for determination of the seismic hazard, dynamic amplification factors of soil media, dynamic properties of structural systems obtained from field measurements, strength and deformability characteristics of structural materials, structural elements and entire structural systems, seismic design criteria and parameters have been defined. Two levels of design criteria based on economically justified damageability and acceptable levels of seismic risk have been established and used as follows: Level I criterion: under the expected seismic effects and a return period of 100 years and peak ground acceleration of  $a(g) = 300 \text{ m/sec}^2$ , the structures should behave in the elastic range without

damage to structural elements but with allowable slight damage to secondary and non-structural elements. Level II criterion: under the expected seismic effects and for a return period of 500 years and peak ground acceleration of  $460 \text{ cm/sec}^2$ , the structures can suffer damages which are technically and economically repairable. This criterion is met by control and limiting of the deformability by dynamic response analysis for different types of earthquake records.

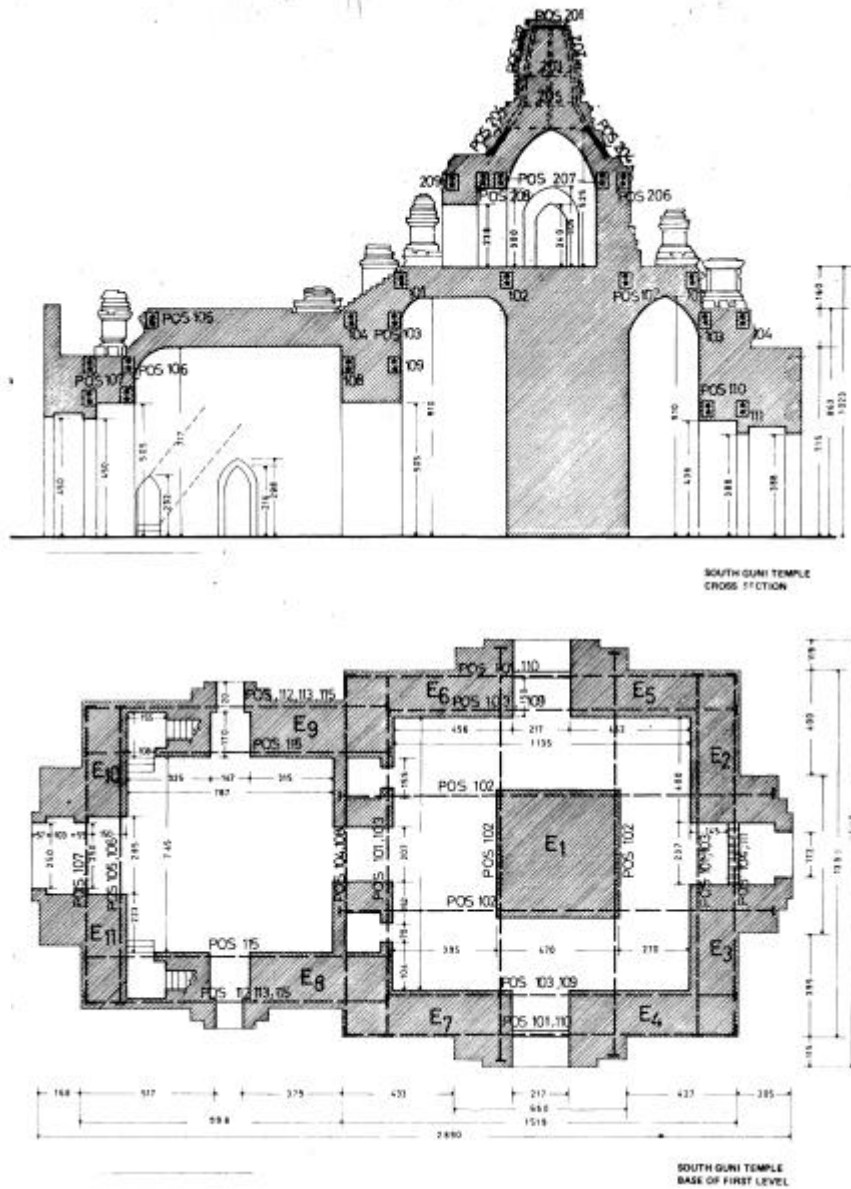


Figure 1. Strengthening of South Guni Temple

Considering, in general, that the monument structures in seismically active regions should not change their basic structural system by the process of repair and strengthening, and in particular, based on the performed dynamic field studies, developed seismic design criteria, and the dynamic response analysis of the monuments in the Pagan region, methods and techniques have been developed in order to provide economically justified and technically consistent seismic safety with sufficient bearing and deformability capacity as well as an acceptable damage level in future earthquakes.

The Pagan region is mainly characterized by two types of historic monuments: temples and pagodas (or stupas). The structural systems of the temples consist of bearing massive walls combined with massive central pillars, which form corridors or halls interconnected with domes or arches. The pagodas are constructed as massive solid stupas with changeable form along the monument height. It is important to be mentioned that large disproportion exists in respect to the size of both the temples and pagodas, starting from the impressive temples (Ananda, Gawdawpalin, etc.) up to 60 m in height, and plan proportions from 50 to 60 m, to the small single-storey temples of about 10 m in plan and height. All the monuments are constructed of solid bricks in mud mortar with or without plastering.

Strengthening of the structural walls (massive and/or medium size) or central pillars has generally been carried out by injection of the existing masonry with cement emulsion, increasing thus the shear resistance capacity to the bending or tension effects. It should be pointed out that the analysis of the load carrying and deformability capacity of the structural systems through equivalent mathematical models and calculations of the load carrying capacities showed that, in most of the cases, the seismic stability criteria of the structural systems satisfy the safety requirements if injection of masonry is applied (due to the massiveness, the size and the proper concept of the structural system) avoiding thus the conventional way of strengthening the masonry by construction of vertical RC columns or frames, which in the case of massive sections proved to be ineffective due to their different bearing and deformability characteristics.

If, in some cases, it becomes necessary to increase the load carrying and deformability capacity of masonry, either of the entire structure or, at some levels, then, the so called "jacketing" method is suggested in order to promote the confinement effect and increase the shear and bending capacity of walls or pillars.

Analyzing the structures and their required stability on one hand, and the technically possible and economically justified methods of repair on the other hand, it has been concluded that the most efficient method of repair and strengthening of the main system is injection. This is the most efficient method in the case of good load carrying characteristics of the bricks since it improves the bond characteristics and improves the bending and shear capacity of the structure, while by inserting bracings and horizontal R/C belts, a good prerequisite has been established for an integral work of the structure and adequate effect distribution according to their stiffness and deformability characteristics.

### 3. EXPERIMENTAL FIELD TEST INVESTIGATIONS

The methodology for repair and strengthening of the monuments in Pagan involves the following techniques: (i) application of reinforced concrete belts and jacketing; (ii) strengthening with steel tied bars; (iii) repair and strengthening by injection (grouting).

Based on the experience in application of this methodology by now, the first two techniques have been accepted and are efficiently applied in monuments restoration. However, in the application of injection of masonry, certain problems arise considering that this technique is relatively new, and also because of the specific constellation and characteristics of the masonry in Pagan.

For the purpose of development of appropriate methodology and techniques for repair and strengthening, two types of field experimental investigations have been performed:

1. Full scale ambient vibration testing on 15 selected monuments for determination of dynamic characteristics including soil media;
2. Structural testing of wall 'in situ' for determination of existing and repair (after jacketing) structural properties and definition of bearing capacity before and after strengthening.

The testing of the walls (Fig.2) has been performed on Monastery building using hydraulic jacks with simulation of cyclic load, and data have been used in the process of repair and strengthening.

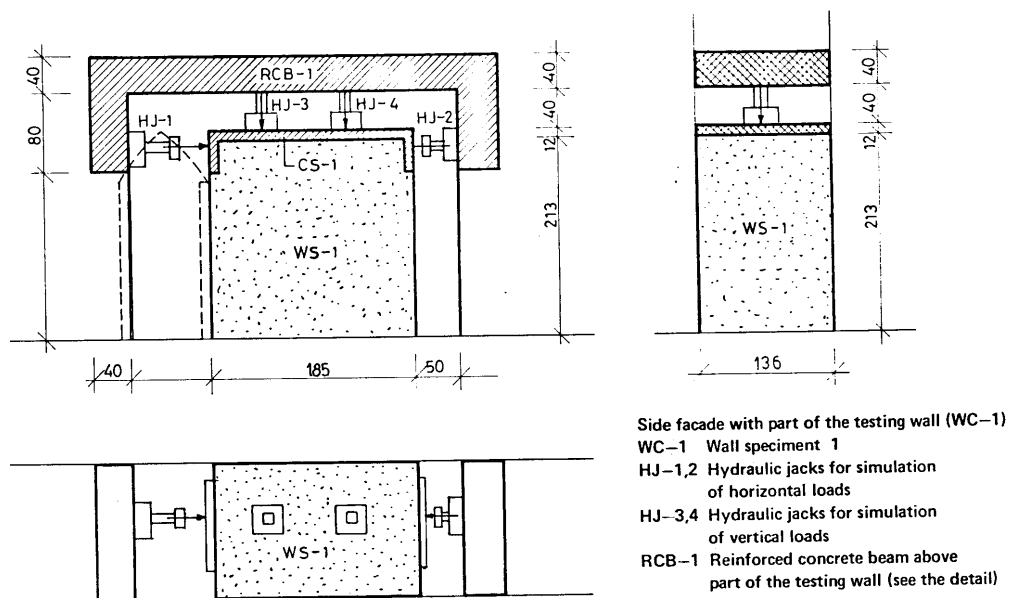


Figure 2. Testing of the wall specimen

#### 4. CONCLUSIONS AND RECOMMENDATIONS

The repair and strengthening of historical monuments constructed in seismic zones should be carried out without introducing any changes or strengthening of the main structural systems/

The proposed method of strengthening by injection is one of the most acceptable ones, improving the load carrying and deformability characteristics, which has also been proved experimentally. Due to the different local characteristics of the built-in materials used for the construction of the temples, their experimental verification is suggested from the viewpoint of both definition of their main characteristics and their economic justification.

#### 5. REFERENCES

- [1] *Methodology for Repair and Strengthening of the National Monuments in Pagan – Burma*, Report IZIIS 83-30/1-6, Skopje, May 1983, UNESCO/UNDP Project BUR 78/023 (Vol. I to Vol. V and Appendix).
- [2] Pichard, P., *The Restoration of Pagan - Burma*, UNESCO Report RP/1975/ 76./3.411.6/.
- [3] Gavrilovic, P., *The Restoration of Monuments in Pagan, Survey and Selection of Monuments for Dynamic Testing and Study for Repair and Strengthening with Assessment of the Record from Pagan Region*, UNESCO Report BUR 78 (023), March - April, 1983, Pagan-Skopje (IZIIS).