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# PRACTICAL REHABILITATION OF BUILDINGS IN CRITICAL CONDITIONS

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## SUMMARY

In high seismicity zones, before the occurrence of earthquakes, some buildings are in critical conditions, due to damage by structural deterioration, lack of maintenance, differential settlements, long term deformations, previous tremors, constructive mistakes, fires or overloads applied due to changes in usage. For these critical conditions, a building rehabilitation methodology is defined and it is shown, that a particular philosophy and the preparation of practical handbooks are necessary, where the principal measures are deformations control, moderate ductility, out of plane effects and low resistance. Besides, some real cases of repair, restoration and rehabilitation of earthen, unreinforced masonry, reinforced concrete and precast buildings made in Venezuela are given.

## INTRODUCTION

In tectonic activity zones, there are buildings vulnerable to earthquakes, built under inadequate codes, criteria or procedures, which do not have a favorable performance under seismic actions. The necessary pre and post earthquake evaluation of existing buildings has conformed an integral rehabilitation conception which includes the phases of evaluation, repair, restoration and strengthening, to which must be added the follow up phase. The evaluation is defined as the methodological identification of the existing capacities and deficiencies to assign certain priority; the deficiencies are conditions which do not conform to the present design and construction requirements. The repair is done to complement the funtionality and can be taken as a punctual resistance funtionality. The upgrade restores the strength before the damage occurs and the strengthening incorporates new resistant elements over a global conception of the structure (IAEE, 1986). The follow up refers to the observed behavior and the verification of the rehabilitation processes. To consider the recycle, the remodel, the changes of use and the treatment of essential and historic buildings, practical handbooks need to be developed according to techniques and codes of a country. The general equation of energy (Bertero, 1992), balances the different termsneeded to meet strategies and procedures that agree with adequate levels of rehabilitation.

$$E_i = ( E_c + E_s ) + ( E_a + E_h ) = E_e + E_d \quad (1)$$

Where the energies are: $E_i$ (seismic); $E_c$ (kinetic); $E_s$ (deformation); $E_a$ (viscous damping); $E_h$ (hysteretic); $E_e$ (elastic) and $E_d$ (total damping). For the practical application of this fundamental equation, a limit states philosophy needs to be defined according to the importance and the characteristics of the building to be upgraded. Sometimes, This application can get quite complicated their application, by the lack of technical information, structural deterioration, no maintenance, differential settlement, long term deformations,

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previous tremors, constructive errors, applied overloads, fire or any other contingency. In these cases, a quick and economical rehabilitation is required, that constrains protective measures be taken, using non sophisticated techniques and practical designs; about which, there is not sufficient information. As codes do not have a retroactive character, the age of the building is the first criterion used to define the vulnerability, and new codes could declare the obsolescense of a building which will lead to a great number of vulnerable existing buildings (Lagorio et al, 1986). It must be considered, that many old constructions are condemned by not having structural systemas and ductile details, but on the other hand, they have sufficient lateral stiffness and high overstrength, in order to remain in elastic condition under the effects of a maximum credible earthquake (Bertero, 1992).

## REHABILITATION PHILOSOPHY

Our codes consider the protection of non-structural elements, the damage control and the security of lifes, under the limit states of service (SLS), damage (DLS) and ultimate (ULS), in order to support minor, medium and strong earthquakes. The definition of the seismic actions is done establishing levels of risk which depend on the useful life, the probability of exceedance and the return period. According to the structural system, type of soil and importance, ductility levels are accepted and permissible drifts are fixed. The fundamentals of earthquake design have been in the use of energy dissipation, ductility and acceptable damage. The owners demand a limitation of economical losses, which imposes the stiffening of the building with excellent results for the use of structural walls (Sauter F., 1996). When the buildings are in critical conditions, a philosophy for rehabilitation should be applied: To have two limit states SLS and SLU with moderate ductilities and a more demanding control of drifts.

## OBJETIVES AND APPLICATION

The rehabilitation seeks to recover the original response by means of the repair of the deterioration and damages; improve the performance of the original structure applying the strength, ductility, stiffnes, regularity and continuity; and reduce the seismic response through the decrease of masses, the incorporation of energy dissipating devices or seismic isolation (Sukano S., 1997). In order to have rehabilitation solutions an adequate inspection, evaluation and diagnosis must be done, that requires measurements, estimates and approximations be made (Uzcátegui y Lobo Q., 1988; Uzcátegui, 1996). The evaluation methodologies are not universal and should adapt to the characteristics and structural type. It is convenient to know the repair and strengthening techniques based on analytic and experimental research in order to reinforce the engineering judgement (Rodríguez M. y Park R.,1991).

## ILUSTRATIVES CASES

In this paper some experiences acquired by the author in Venezuela are shown in the repair and strengthening of different buildings, applying everything or part of the mentioned objectives. Repair: R-1. Cracking of structural slab. Táriba. Restorations: R-2. Church of earthen walls. Barinitas. R-3. Church of masonry. Mérida. R-4. Precast unit of hospitalization. Mérida:

**R-1. Building Nº 4. Residential Block, Táriba (Lobo Q., 1987)**

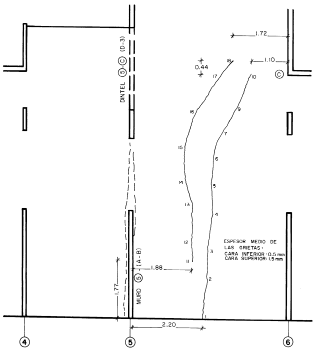


Fig. 1. Cracks on the slab (R-1).

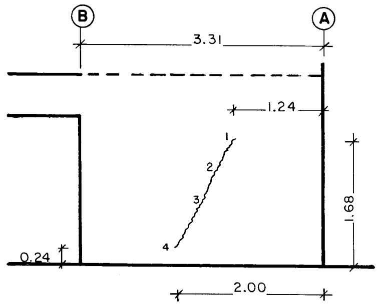
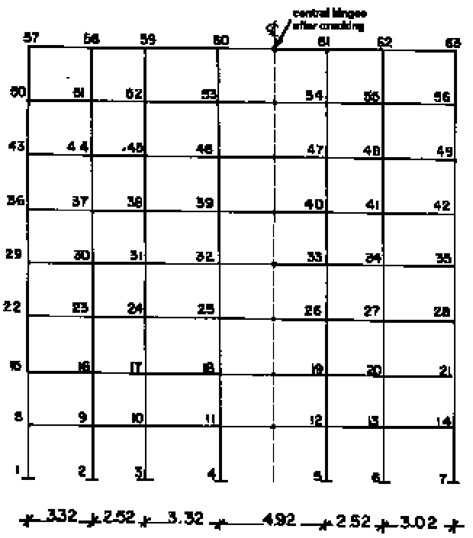



Fig. 2. Cracks on the left wall (R-1).



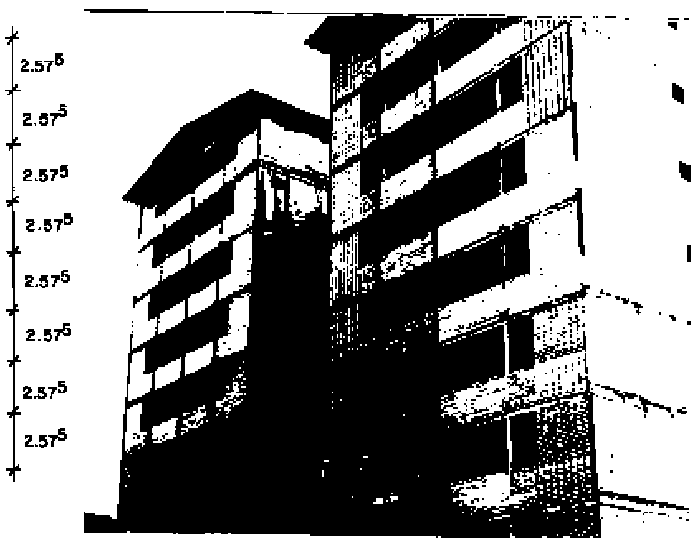



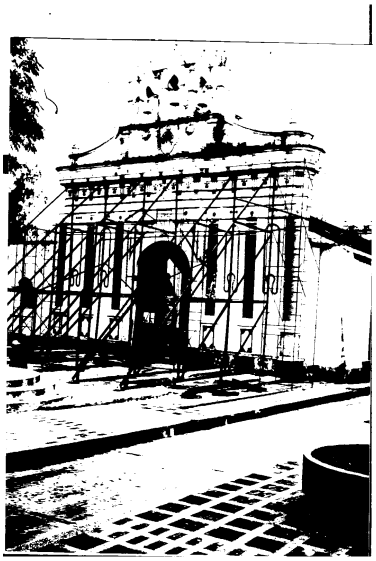
**Fig. 3. Principal frame of the building (R-1).** **Fig. 4. Residential Block repaired (R-1).**

A building in construction with structural walls (tunnel type) of 12 cm. of thickness and slabs of 15 cm. After the pouring of the concrete and the removal of the forms at the first story, in the central span a provisional support was left during two months that changed the sign of the moment, and produced cracks that were incremented by skrinkage. The cracks on the slab were two central and symmetric cracks (Fig. 1); and other crack in the structural wall (Fig. 2). A structural frame model was processed for vertical loads and another 3-D model (Vlasov Method) for seismic forces (Fig. 3). Also, frames with central hinges were solved to understand the cracking of the wall. It was resolved to inject the cracks with epoxy remove the cover concrete and reinforce both faces of slab. The building repaired it show at the Fig. 4.

**R-3. Barinitas Church (Lobo Q., 1990).**

This is a church built with earthen walls and adobe bricks, whose wooden roof and tiles were removed during the rainy season. This dereriorated walls, counterforts and plaster, cracked the arcades of the altar and rocked the frontis considered of historic value. The cracking of the arches was accelerated by the lateral pressure. The shoring of the frontis, was recommended to stop the rocking against vibrating movements, impact or seismic

effects (Fig. 4). Crown beams were built on top of the earthen walls in horizontal rings, anchored at the corners and intermediate supports
(Fig. 5).



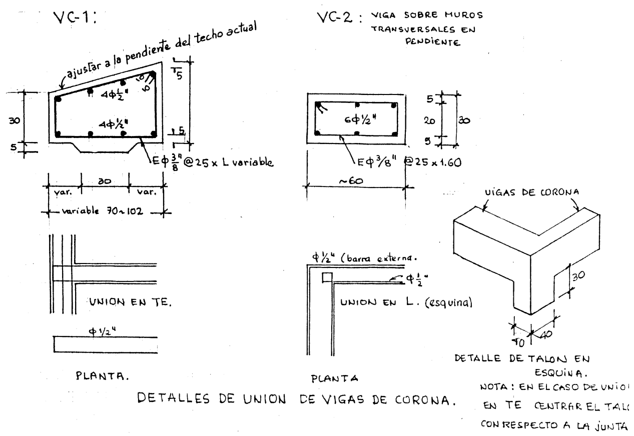



**Fig. 5. Frontis of Barinitas Church (R-2). Fig. 6. Details of crown connection beams (R-2).**

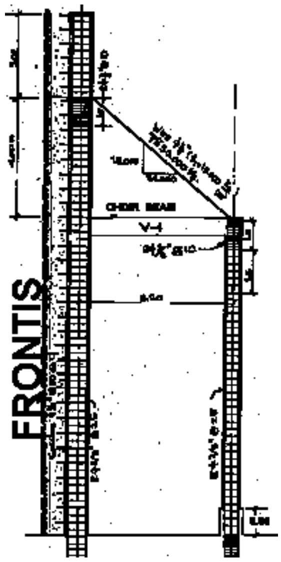



**Fig. 7. Detail of the Choir against the Frontis (R-2).** **Fig. 8. The Church in construction (R-2).**

**R-3. Corazón de Jesús Church, Mérida (Lobo Q., González B.,1988).**

**Fig. 9. Original Facade (R-3).**

**Fig. 10. Rehabilitated Facade (R-3).**

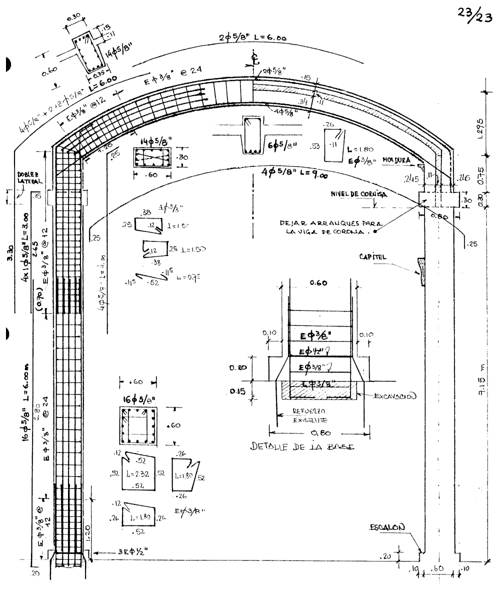



**Fig. 11. Principal arched frame (R-3).**

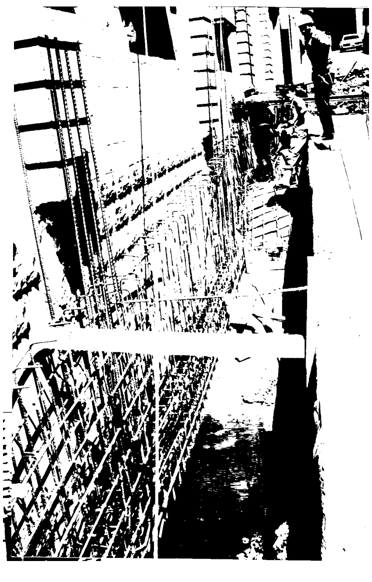


**Fig. 12. Lateral Wall (R-3).**

This is a building of masonry walls with and arched roof of thickness 11 cm., span of 8.5 m. and a dome of 6 m. height, 15 cm. of thickness and 7.5 m. of diameter (Fig. 9). The damages in the masonry columns (60 cm x 60 cm. and 7.5 m. de heigth), began by the dynamic lateral pressure generated by the traffic, and the horizontal push of the

arched roof. The dome showed cracks in the meridians occasioning rupture of the beams that transmit their loads to the arches. The choir was built against the Frontis of a wooden and brass structure, with fractured masonry columns; which was substituted by a reinforced concrete structure.

This church was found in a state of progressive deterioration, lack of maintenance, filtration of roofs, lateral overloads due to traffic and frequent of the continuous tremors (Fig. 13). .The global evaluation recommended inmediate shoring; the columns were substituted for a reinforced concrete arched frame (Fig. 11), with crown beams over the walls. A system of spread foundations was designed with double beam conections and retaining walls on the side street. The arched roof was substituted totally eliminating the exterior beams (Fig. 10 and 12).

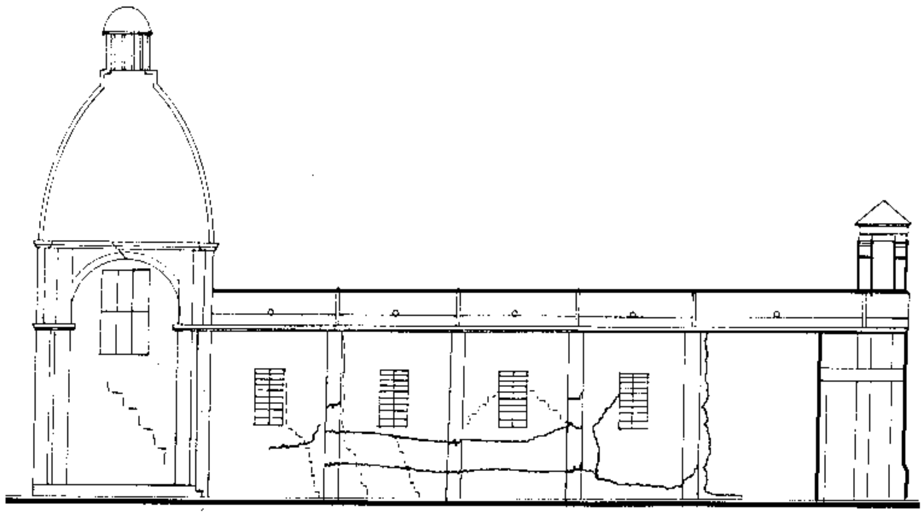


**Fig. 13. Cracks in lateral facade of the church (R-3).**

**R-4. Social Security Hospital, Mérida (Lobo Q., Gonzalez B., 1986)**

This building has two blocks, one of these with three floors, the first floor of reinforced concrete and the others with precast concrete type "Varinueva" of U shaped with extremal frames, longitudinal beams and a connection slab (Fig. 14 and 15). A high seismic torsion in the basement, no connection and disalignment of elements, vertical discontinuity and deficient support. The cracks were injected cavities were filled with epoxies, walls were built on the ground level, the topping of slabs to uniformize and rigidize the diaphragm, steel plates were attached to reinforce beams; columns were reinforced using jacketing with transvese ties. To design and reinforce the columns ultimate strength interaction diagrams was prepared (Fig. 16) The non rehabilited structure is shown in Fig. 17, and the rehabilited building in Fig. 18.

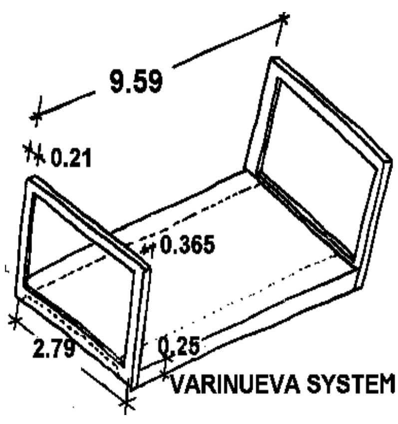



**Fig. 14. Detail of Varinueva System (R-4).**

**Fig. 15. Frefabricated building in construction (R-4)**

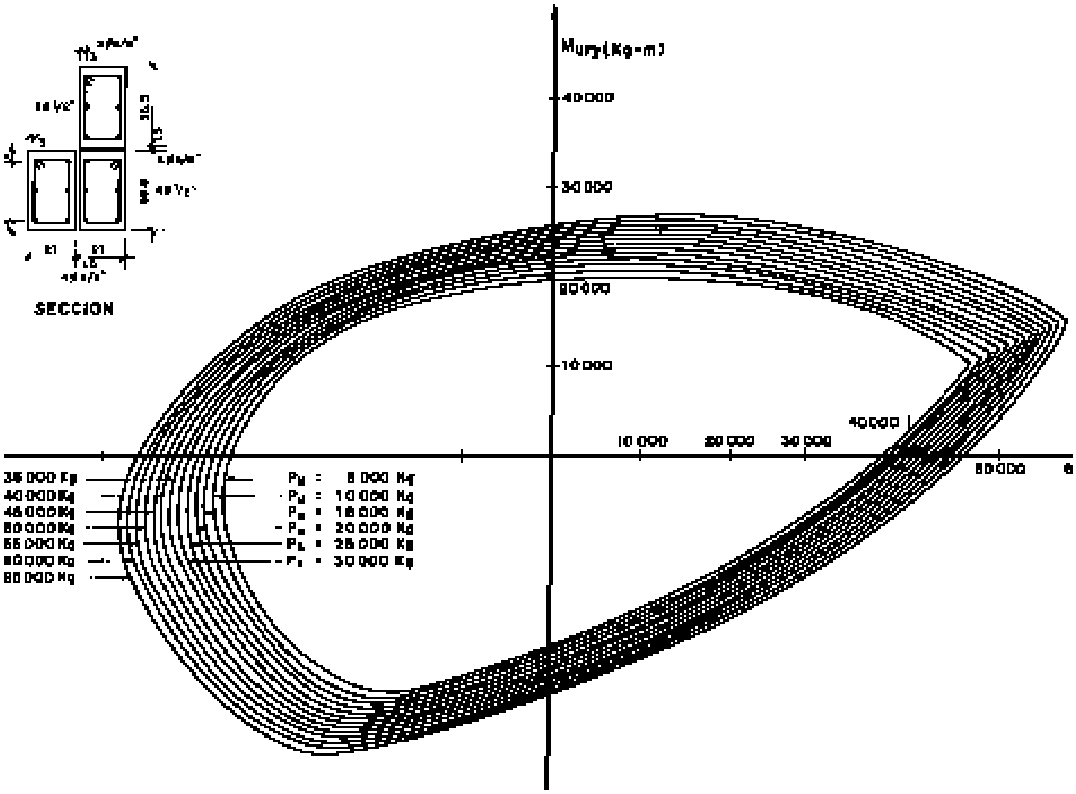



**Fig. 16. Interaction Diagrams for three columns of the Varinueva System (R-4).**

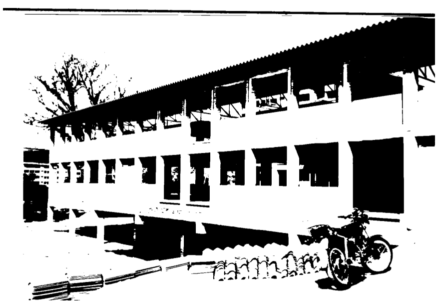


**Fig. 17. Hospital to rehabilitate. (R-4).**

**Fig. 18. Rehabilitated Hospital (R-4).**

## ANALISIS AND DISCUSSION

These repair cases show the need to avoid the changes of behavior upon the intervention, know the constructive techniques applied to structural pathology, the characteristics of special products and new applied materials; which should be object of university teaching. Besides, the knowledge about non destructive tests should be included. Mainly, the analysis is made with static or dynamic elastics methods, although the elaboration of capacity curves

(pushover) with static non linear procedures is recommendable (FEMA, 1996). Generally, a building in critical or

deteriorated conditions requires an inmediate shoring. A load test should be made only in extreme cases with verified weakness. This should be done by qualified personel when all involved parties mutually agree. There are still doubts about earthen construction because of the incorporation of beams, anchorages and other steel and concrete elements. The necessity to have methods and criteria to obtain the adequate maintenance of buildings and avoid critical conditions is clearly established. More experience is needed in the follow up of rehabilitated structures.

## CONCLUSIONS

1. A design philosophy need to be defined that undertakes the pre and post-seismic rehabilitation of buildings in critical conditions.
2. The existing buildings in critical conditions lose the aseismic capacity and their rehabilitation requires the preparation of practical handbooks. Principally the measures involved are deformation control, moderate ductility, out of plane effects and low resistance.
3. In the damage diagnosis, the identification of upgrading and the rehabilitation strategies, the original concep-tion and the ocurred behavior must be harmonize with the constructive process of stiffening or strengthening.
4. The stregthening of different materials requires the knowledge about structural pathology techniques, the new special products and the applied materials. In repair processes or upgrading, detailed constructive drawings must be used or good engineering judgement to represent the real conditions.
5. The intervention caused by incorporating new structural components that change the global perfomance of the existing structure needs to be considered carefully.

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