PROGRESS REPORT I

May-October 2001

NATO-SW 977231

SUB-PROJECT 2

REHABILITATION METHODOLOGY DEVELOPMENT

1. INTRODUCTION

The seismic repair and/or strengthening philosophy generally consist of system behavior improvement and member repair/strengthening In the system behavior improvement technique, a new lateral load carrying system is introduced to increase the lateral strength and the lateral stiffness of the existing system. Besides overall system improvement, if the capacities of reinforced concrete elements are rot sufficient against lateral loads, their repair and or strengthening is required. The scope of this sub-project is to develop new strengthening techniques.

The major activity planned for this initial stage of the present sub-project was planning of the experimental investigation. Actual testing bad been planned to start in the following period. Experimental work planning has been completed to a great extent. Furthermore, two tests have already been performed, and the data processing is in progress.

1.1 Strengthening Principles

The two basic approaches chosen in the planning workshop for the seismic retrofitting of the existing undamaged reinforced concrete building structures were:

- Strengthening of the existing hollow brick masonry infills by CFRP and
- Use of post-tensioned diagonals in the chosen frame bays

to increase the lateral stiffness and thus to improve the seismic response of the existing structural system, since insufficient lateral stiffness is the most common seismic deficiency in this kind of structures in Turkey and in the other countries of the region. A critical evaluation of the latter approach indicated some serious drawbacks of this technique, which caused concern about the potential problems expected in practical applications. It was therefore decided not to give priority to this approach and consider it as a secondary alternative, which may be studied, if time allows. However, another technique was adopted as the second basic approach:

- Strengthening of the existing hollow brick masonry infills by introducing one or two layer precast concrete panels (small enough to be carried by two workers) in-situ connected to each other and to the existing reinforced concrete frame elements to act as a reinforced concrete infill.

1.2 Testing Principles

Considering the laboratory facilities available, majority of the tests are planned to be performed on two-dimensional, one-bay, two-storey, one-third scale reinforced concrete frame models under reversed cyclic quasi-static loading. These two-storey frames are considered as the lower floors of multistory building structures. However, the effects of various modeling parameters will be investigated by different types of verification tests. Some selected tests will also be performed on three-bay frames to justify the generalization of the results obtained from one-bay frames to multi-bay frames. Similarly, a few full scale models will also be tested to investigate the scale effects on the results. One three-dimensional shake table test has also been planned to be performed under an actual earthquake excitation in Skopje, Macedonia. The test set-ups to be used are briefly introduced in the following paragraphs.

- **Horizontal One-bay Twin Frames (METU & BU)** - This rather simple test set-up had been developed more than a decade ago using rather limited testing facilities and employed in three PhD and half-a-dozen MSc theses. The model consists two identical one-bay two-storey frames monolithically connected to the two sides of a heavy foundation beam, Figure 1. The model is supported at the ends of the top floor beams as a simple beam and loaded at the other end of the foundation beam in a horizontal closed loading frame. The equal reactions of the simple beam carrying a central concentrated load represent the horizontal seismic load applied at the second floor level- Vertical load is applied to the columns by means of two rigid steel box beams pulled towards each other by post-tensioning cables as schematically shown in Figure 1.

- **Vertical One-bay Frames (METU)** - One-bay two-storey frames identical to one half of the twin frames are erected in front of the strong wall and their foundation beams are rigidly attached to the strong floor. A double acting hydraulic ram, pin connected to the top floor beam and the strong wall, applies the reversed cyclic quasi-static load representing the seismic effect as schematically shown in Figure 2 .

- **One-bay Full-scale Frames (ITU)** - The supporting and loading systems are very similar to the preceding test set-up. The major differences are the (i) higher capacities of the testing equipment enabling testing of a full-scale model and (ii) single storey test frame.

- **Three-bay Frames (METU)** - Three-bay two-storey frames having similar properties as the vertical one-bay METU frames are tested in vertical configuration under reversed cyclic load applied by double acting hydraulic jacks bearing against the strong wall, as schematically shown in Figure 3. Since the degree of indeterminacy of the structural system is much higher than that of the one-bay frame, column reactions need to be measured. A special reaction transducer has already been developed and tested, so that it will be used at bases of the two exterior columns. Such transducers are not needed for interior columns, since the infill is placed in the central span.

2. CFRP STRENGTHENED MASONRY INFILLS (METU & BU)

The existing hollow brick walls are strengthened by CFRP (carbon fiber reinforced plastics) application expecting that after this improvement the infill wall will significantly contribute to the lateral stiffness of the frame, and this process will also prevent the brittle failure of the brick masonry, improving the behavior by increasing the ductility. The parameters to be considered in this group of tests are listed below and a few typical examples currently being studied are shown in Figure 4 :

- **Extent of CFRP Application** - A CFRP blanket applied to the brick wall alone is expected to delay cracking in the wall and thus to lead to a marginal improvement in the ductility and the strength. A CFRP blanket, extended to the reinforced concrete elements and bonded to the beams and columns, is on the other band, expected to be far more effective, since it will probably serve as a tension diagonal in either direction and thus improve the lateral stiffness significantly, besides strengthening the brick wall.

- **Number of CFRP Layers -** Two CFRP blankets applied to either side of the wall will naturally confine the masonry and consequently lead to a higher level of improvement. However, the rather high cost of this material justifies the investigation of the possibility of single layer application.

- **CFRP Covered Area -** If tension diagonal behavior of the CFRP bonded to the reinforced concrete members proves to be very effective, the possibility of using diagonal strips instead of full blankets needs to be investigated due to reasons of economy. In such a case, the band width will unavoidably be a parameter to be carefully investigated.

- **CFRP Anchorage Techniques** - CFRP itself and the bonding agent (glue) have very high strengths and are capable of carrying very high stresses. The anchorage has to be strong enough to transfer these rather high forces to the supporting elements. These forces will inevitably cause very high shear stresses in the concrete or the plaster, and stripping a thin layer of concrete or plaster, which has a low tensile strength will not be unlikely, unless an effective technique is developed to ensure proper anchorage of the two ends of the CFRP band.

- **CFRP Orientation** - A CFRP blanket consists of at least two layers with fibers arranged in two orthogonal directions. The natural and effective way (minimizing the waste of material) is the use of this kind of orthogonal reinforced blankets. However, a specially oriented (in the directions of the diagonals) carbon fiber reinforcement may be more effective in the cases where the tension diagonal behavior is the dominant factor of improvement.

2.1. One-Bay Frame Tests (METU & BU)

The blanket type CFRP strengthening concept explained above will be investigated by experiments on two-storey twin frames horizontally tested in closed loading frames. Most of the above mentioned parameters will be studied in the Structural Mechanics Laboratory, METU and some in BU.

2.2. Completed Tests (METU)

Six one-bay two-storey twin frames belonging to the CFRP blanket strengthening category have been produced in the laboratory, and two of them have already been tested under reversed cyclic load applied in the horizontal closed loading frame.

The first one was the reference specimen, which was intentionally designed as a weak frame reflecting the deficiencies of common poor practice observed especially in low rise residential buildings in small towns. Hollow brick wall was again typical of the common practice. A layer of typical plaster covered both the wall and the frame. Since it was the reference specimen, no measure of strengthening was applied to this frame. The observed behavior and strength conformed to the expectations, and they will be used as references in comparison with those of the retrofitted specimens to be tested later.

The second one had identical properties as the reference specimen, however, its infill walls were covered (no extension to the frame members) with CFRP blanket on both sides. The observed behavior was marginally better compared to the reference specimen and the strength was slightly higher.

2.3. Full-Scale Verification Tests (ITU)

When a reasonably clear idea is obtained about the efficiency and effectiveness of the CFRP strengthening technique, some carefully selected tests will be repeated on full-scale models, to investigate the effects of scale on the results, before drawing any generalized conclusions.

2.4. Three-Bay Frame Tests (METU)

With the intention of understanding the actual multi-bay frame behavior after introduction of the CFRP strengthening, some of the tests, which have already been performed on one-bay twin frames will be repeated on three-bay frames vertically tested under reversed cyclic load applied by a double acting hydraulic ram bearing against the strong wall.

3. PRECAST PANEL STRENGTHENED MASONRY INFILLS (METU)

This seismic strengthening approach using conventional materials is expected to provide a more economical solution to the problem of retrofitting of the building structures still in use, without causing much disturbance to the occupant, Instead of replacing the brick wall by a cast-in-situ concrete infill panel, a concrete infill is formed, on either one or both sides of the existing masonry wall, by in-situ connecting precast concrete slabs of manageable size to each other and to the surrounding reinforced concrete beams and columns. The parameters to be considered in his group of tests are listed below:

- **Number of PC Panel Layers** - Depending on the properties of the specific structure being strengthened, (i) a single and relatively thick (80-100 mm) infill layer may be formed on one side of the existing brick wall or (ii) two relatively thin (40—50 mm) PC layers may be used on either side of the wall.

- **Panel Size and Geometry** - Precast concrete slabs should be small enough to be carried by two workers. The slabs forming the infill panel when connected together should have a suitable geometry and size. Various alternatives may be developed for the specimens of this test series.

- **Connection Details** - The most important and complicated problem of this technique is obviously the connection details. Connections need to be sufficiently strong to provide a solid and rigid infill behavior; they must be simple enough not to require expert workmanship; last but not least, they also need to be economical. Various possibilities are being considered towards developing various connection detail alternatives, which will be experimentally investigated.

This group of tests is planned to be performed mainly on vertical one-bay two-.storey frames subjected to reversed cyclic load applied by a hydraulic jack supported by the strong wall. However; one or two verification tests may also be realized on three-bay frames.

4. PROGRESS EVALUATION

4.1. Accomplishments

Considering the timetable given in the project plan, this sub-project appears to be ahead of schedule. Planning of the experimental investigation was expected to take place in this initial stage of the present sub—project. Besides experimental work planning completed to a greet extent, actual testing have also started, and two tests have already been performed.

4.2. Future Plans

The sub-project appears to be progressing well in conformity with the work schedule. No change of plans is therefore proposed at this stage.

4.3. Young Scientists

The P1 of the present sub-project is a young scientist (an assistant professor) himself. Two other young assistant professors are leading the research teams in ITU (Istanbul Technical University) and BU (Bosphorous University).

Two PhD and five MSc students have already been engaged in METU; three of them are actively working on various aspects of the project. One MSc student in ITU and one in BU have also received their thesis assignments concerning the planned tests.

4.4. Travel

In line with the resolutions of the organizational meeting held in May, the principal investigator of the present sub-project will participate in an international conference on FRP composites used in civil engineering to be held in Hong Kong in December 2001.

4.5. Proposed Changes

No change of plans is proposed at this stage.

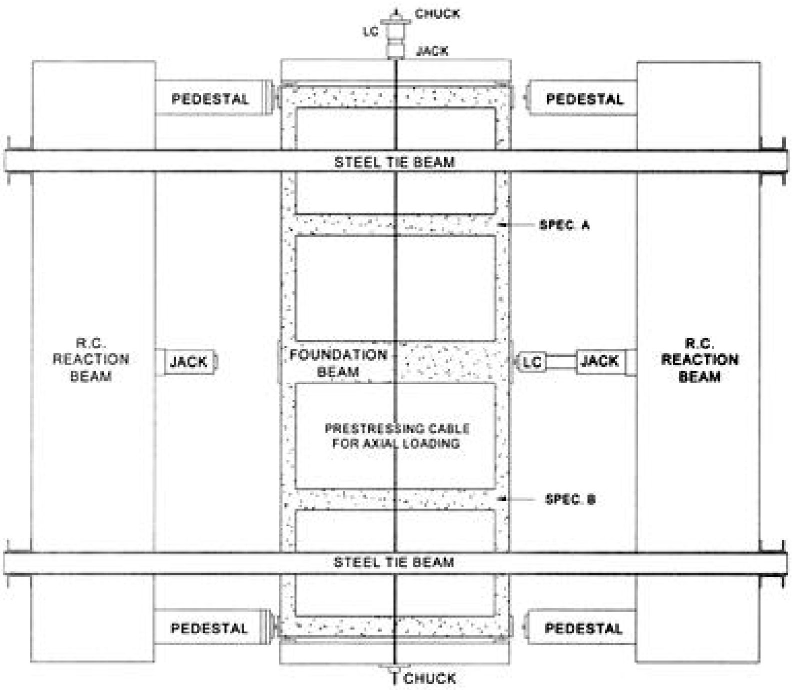


Figure 1. Horizontal one-bay twin frame

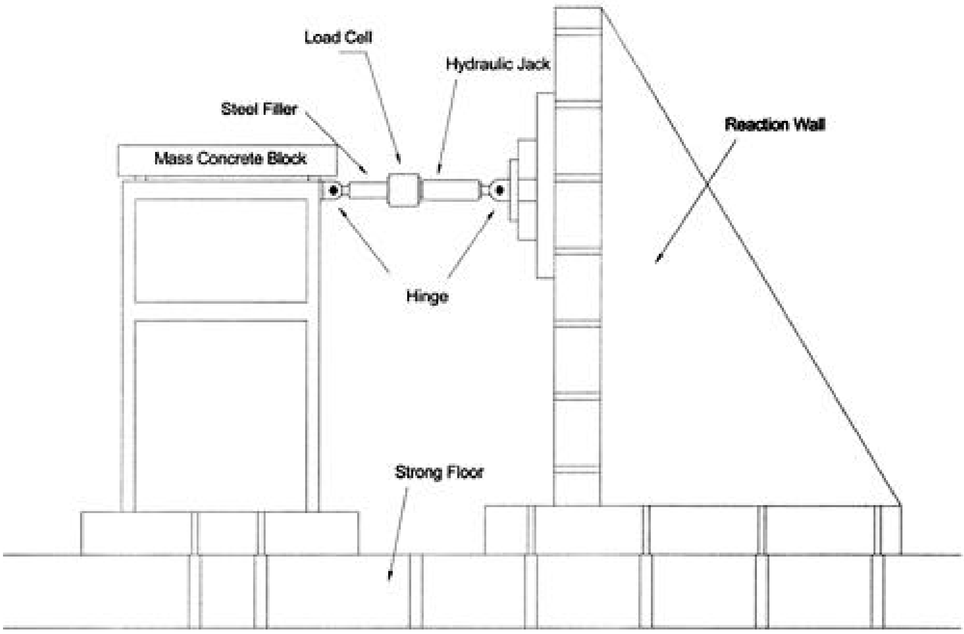


Figure 2. Vertical one-bay frame

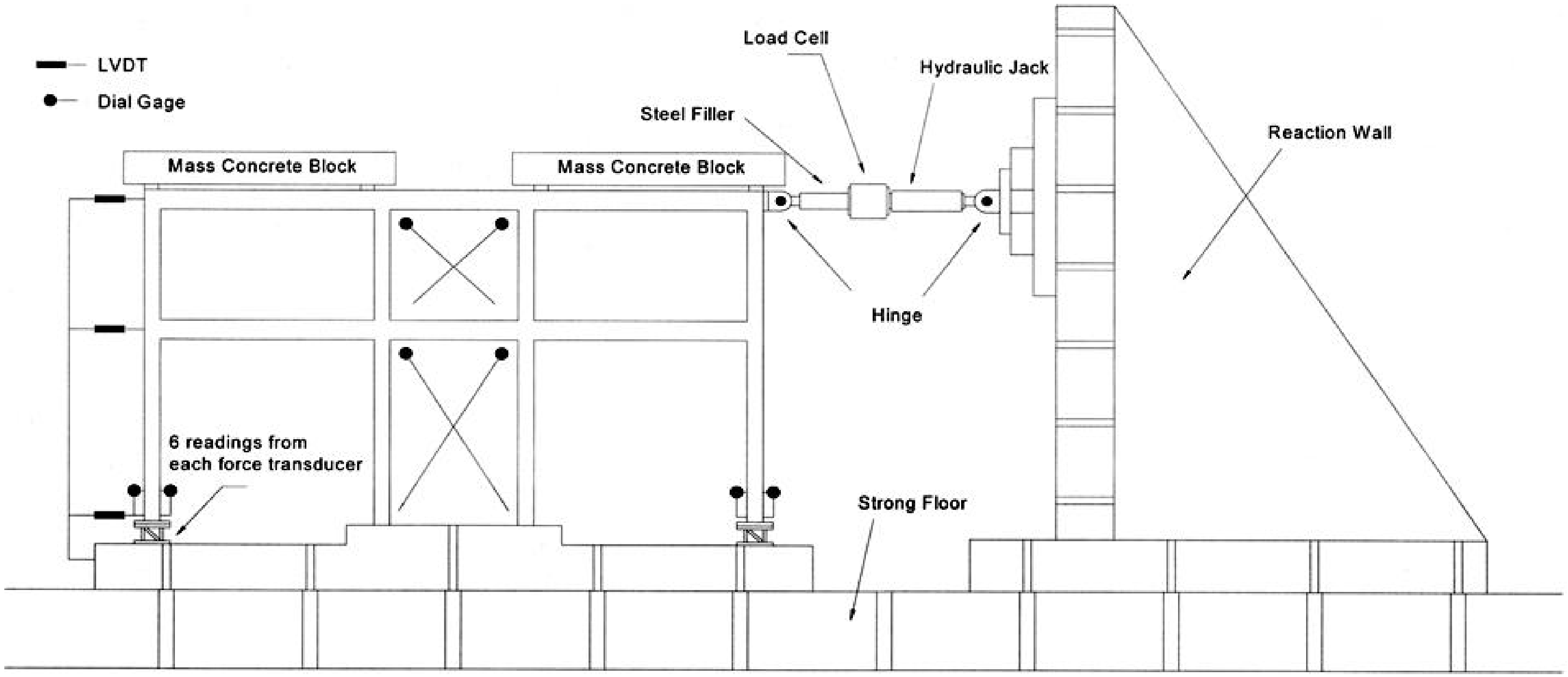
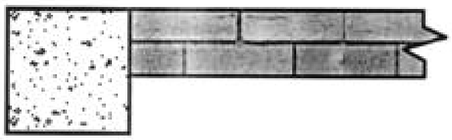


Figure 3. Vertical three-bay frame



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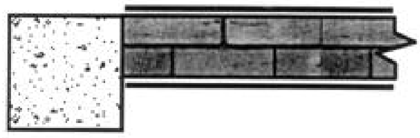
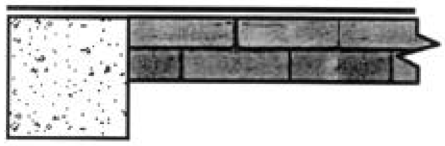


CFRP strengthened



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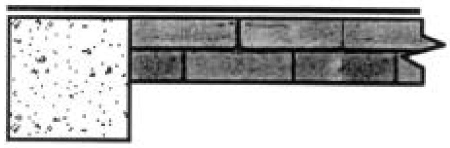
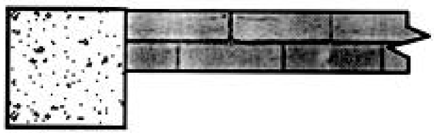
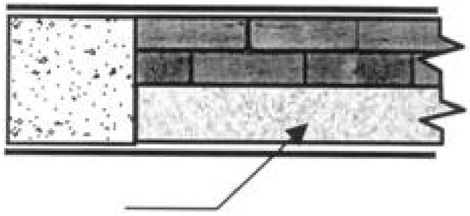


CFRP strengthened



CFRP strengthened



CFRP strengthened

Figure 4. CFRP Strengthened masonsry Infills