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EARTHQUAKE RESISTANCE OF MASONRY STRUCTURES STRENGTHENED WITH FIBER COMPOSITES

G. Schwegler and P. Kelterborn

Ernst Basler & Partners Ltd., Zollikerstrasse 165, 8702 Zollikon (Switzerland),
and Rainstrasse 372, 8706 Meilen (Switzerland)

ABSTRACT

Two 60 year old, adjacent 6-storey residential buildings in the city of Zurich, Switzerland, are presently converted into an office building. Major changes to the structural system were necessary; in particular, some load bearing walls had to be replaced or reinforced to resist potential earthquake forces. The reinforcement is carried out by carbon fiber reinforced plastic sheets (CFRP). The CFRP-sheets are glued to the existing shear wall and anchored in the RC-slabs. The earthquake resistance can thus be enhanced manifold. Prior to the application of this strengthening method, numerous large scale tests were carried out at the Swiss Federal Laboratories for Materials Testing and Research EMPA, which confirmed its efficiency.

KEYWORDS

Masonry, Strengthening, Carbon Fiber Sheets (CFRP), Earthquake Resistance, Reconstruction, Shearwalls

INTRODUCTION

In recent years, engineers are more often faced with the reconstruction or upgrading of existing buildings rather than designing new ones. Although it would be more economical in some cases to replace a building completely, city planning regulations and historical reasons do not allow to do major changes to many buildings, especially on facades. As most of the older buildings are not designed to resists earthquake forces, architects and engineers are challenged to find economical solutions to make structural systems and the structural elements earthquake-resistant. Especially when the usage of a building is changed from living to office space and shopping areas, major changes of the structural system are required. Consequently, old structural elements are replaced by new ones, or they have to be strengthened. In many cases it is desirable to maintain as many old structural elements as possible if the they can be strengthened economically, i.e. without undue interference with other remaining structures or the usage of space.

In the city of Zurich, two adjacent 60 year old residential buildings of 6 storeys are presently converted into one office building. Major structural changes are necessary. Old wooden slabs are replaced by RC-slabs. Load bearing masonry walls are partly eliminated and replaced by new ones. Some of the remaining load bearing masonry walls are strengthened by using carbon fiber sheets, so that the earthquake load can be resisted. The carbon fiber sheets are glued to the masonry wall and anchored in the slab. This strengthening method has been tested in full scale tests at the Swiss Federal Laboratories for Materials Testing and Research EMPA. These tests showed a significant increase in strength and ductility of the CFRP-strengthened masonry wall elements. As it is easy to apply and economical, this strengthening method is very promising.

In the following, the application of the above mentioned method of strengthening masonry walls by CFRP-sheets is demonstrated (Ernst Basler & Partners Ltd., 1995).

RECONSTRUCTION PROJECT

Two adjacent residential buildings are functionally joined so that they can be used as offices (Figure 1). All structural elements are affected by this conversion. Only a small number of them remain more or less untouched. All inner walls are removed. The outer wall on the rear side of the building is replaced by a light weight construction. The facade looking onto the main street (called Mühlebachstrasse) has to be retained. However, in the center part a large window is created. On the ground floor level, the load bearing walls are replaced by a new arrangement of columns to create shop windows (Figure 3). The fire protection walls separating the neighboring building remain.

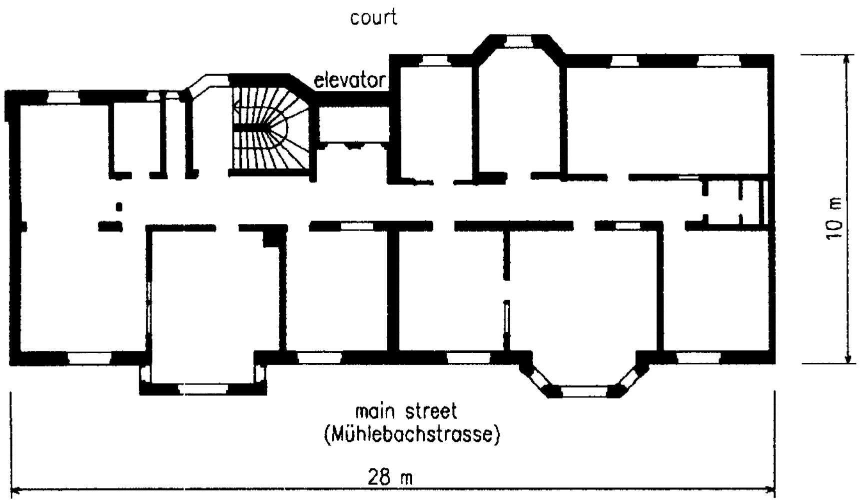

Figure 1: Existing bearing structure on 2nd floor, before remodeling

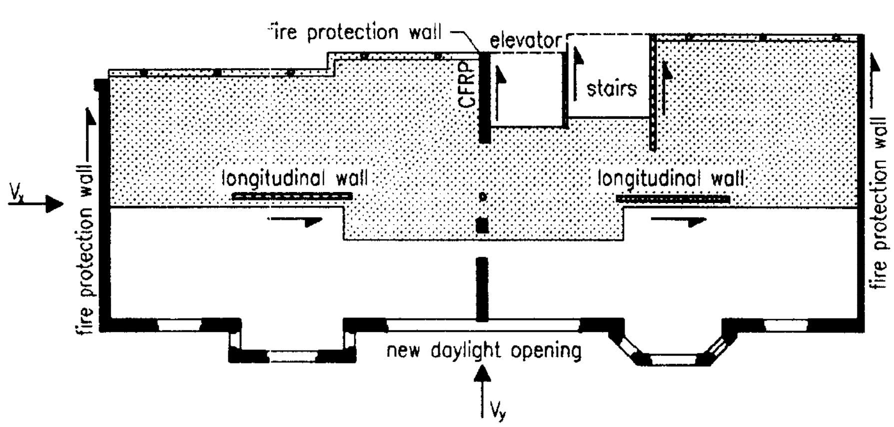

Figure 2: Bearing structure 1st to 4th floors, after remodeling

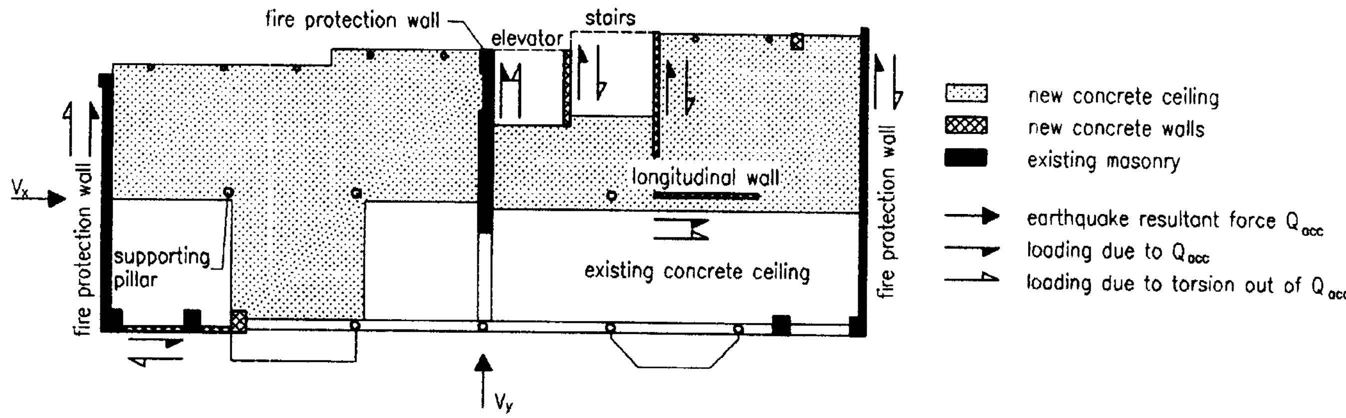

Figure 3: Bearing structure ground floor, after remodeling

These major changes to the structural system lead to a markedly different dynamic behavior as before. Both the stiffness and the strength have thus been altered, which had to be considered in the design against earthquakes.

EARTHQUAKE RESISTANCE

The major horizontal earthquake forces act at the floor levels. The floor slabs have to be stiff and strong enough to transfer these forces into the shearwalls, from where they are carried to the foundation. In the transverse direction of the building, the lateral resistance is provided by the shear walls of the stair case, the fire protection walls of the elevator shaft and by the double masonry wall to the adjacent buildings. In this direction, the stiffness, mass and strength are more or less symmetrically arranged.

In the longitudinal direction there are two load resisting walls in the center of the building from the 1st to the 4th floor. On the ground floor level, one of these two walls is replaced by an eccentric wall in the facade. Should it come to an earthquake, this leads to significant torsion in the longitudinal direction. To balance this torsion, the structural elements in the transverse direction need to be taken into account.

The existing wooden floor slabs are not rigid and not strong enough for the lateral load transfer and have thus to be partly replaced by RC-slabs. The large lateral forces on the shear walls of the elevator shaft required a strengthening which was done using carbon fiber sheets.

CHARACTERISTICS OF THE CFRP STRENGTHENING MATERIAL

The CFRP-sheets are a combination of unidirectional high strength carbonfibers with an epoxy resin matrix. This leads to a material of high strength and stiffness. CFRP-sheets are produced in strands of unlimited length by the pultrusion-process and delivered to the site of application in rolls.

CFRP-sheets have major advantages over sheets made of steel. CFRP-sheets are superior with respect to corrosion, fatigue behavior and strength. In addition, they are light and easy to handle and simple in the application.

The most relevant material characteristics of the CFRP-sheets are shown in table 1.

Table 1: *Major material properties of CFRP-sheets as compared to steel-plates*

Type of strengthening material	Ultimate tensile strength σ_u [N/mm^2]	Young's Modulus E [N/mm^2]	Ultimate tensile strain ε_u [%]
C-Fiber T700S	2300	152'000	1.50
steel	235	210'000	> 5%

Compared to steel, CFRP shows linear elastic material properties, and the ultimate tensile strain of the applied CFRP-sheets amounts to ε_u = 1.5%. These material properties have to be taken into account during the planning process. The large scale tests conducted at EMPA show that with an appropriate distribution of the CFRP-sheets on the masonry wall, considerable system's ductility can be achieved.

APPLICATION OF THE CFRP-SHEETS

In the special case of this 6-storey building, the CFRP-sheets are applied cross-wise on the surface of one side of the masonry wall (Figure 4). Before applying the sheets, the surface has to be smoothened by sanding and by filling the holes with epoxy mortar. Small holes are filled with the epoxy resin applied with CFRP-sheets. The sheets are pressed onto the surface of the masonry wall by means of a stiff aluminum beam.

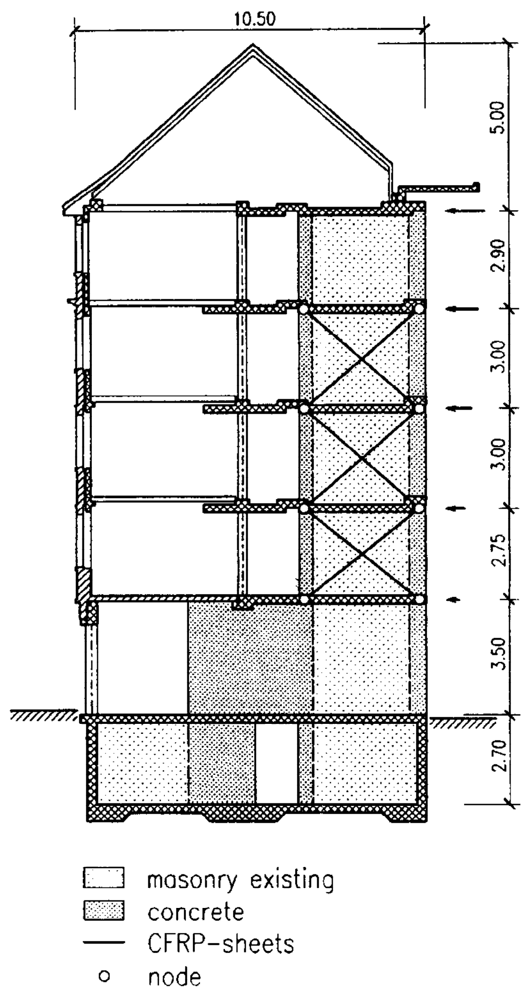

Figure 4: Distribution of CFRP-sheets on masonry shear wall

The CFRP-sheets are anchored in the new RC-slabs above and below the wall. Due to the anchoring in the RC-slabs, stress concentrations in masonry walls are avoided. The anchoring of the sheets in the RC-slab consists of a steel plate which is pressed onto the ends of the sheet by means of bolts. These are placed in the shuttering together with the reinforcing bars before pouring the concrete (Schwegler G., 1994a). The heads of the bolts are spared out by styropore, in order that the plate can be pressed onto the hardened concrete by tightening the bolt. Afterwards, the recesses can be filled with mortar (Figure 5).

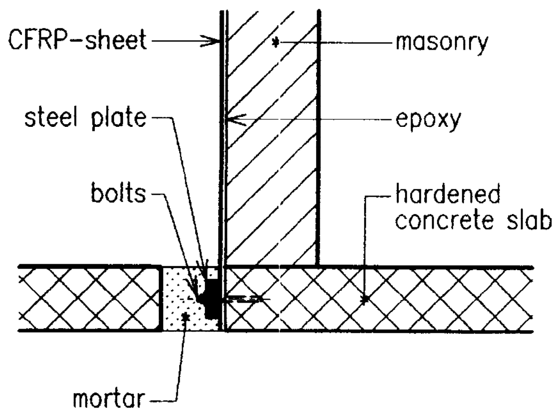

Figure 5: Anchoring the CFRP-sheets in the RC-slabs

It is sufficient to use the CFRP-sheets only on one side of the wall. The amount of work is thus limited. The tests at EMPA have shown that eccentricity causes negligible effects on the strength of the shear wall (Schwegler G., 1994a).

The anchoring of the CFRP-sheets in RC-slabs or eventually in the columns is most important. At present, an anchoring system that can be easily and economically applied to any situation is being developed and tested by the consulting company Ernst Basler & Partners Ltd. and at EMPA.

The design calculations to determine the strength of the CRFP-reinforced masonry wall is done by the Stress Fields Theory which is described in detail in references (Schwegler G., 1994a) and (Muttoni A. et al, 1988).

CONCLUSIONS

The application of CFRP-sheets to the existing load bearing masonry shear wall significantly increased its lateral resistance and ductility. Alternative methods such as reinforced shotcrete or the replacement of the wall would have been more expensive. Besides, a reinforced shotcrete strengthening would have lead to an additional thickness of 700 mm, which for architectural reasons would not have been acceptable.

The CFRP reinforcing method for masonry walls proves to be a very efficient method in the field of earthqake resistance design, as it economical and easy to apply.

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