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CONSTRUCŢII. ARHITECTURĂ

REHABILITATION OF EXISTING STRUCTURES SUBJECTED TO EXTREME EVENTS

BY

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The paper presents the characteristics of existing structures under extreme actions, general and specific rehabilitation solutions detailed for reinforced concrete and masonry structures. Rehabilitation of different types of existing structures are described: a reinforced concrete framed structure presenting major detailing vulnerabilities at seismic actions; an apartment house affected by an explosion; two masonry buildings affected by a recent earthquake.

1. General Solutions for Rehabilitation

1.1. Rehabilitation Solutions for Vertical Irregularities

The main solutions consist of:

a) strengthening of the existing structural elements and/or of the structural system by increasing the strength stiffness and ductility of the weak structural elements;

b) including additional structural elements.

For both solutions it is necessary to avoid new stiffness discontinuities under lateral displacement. On the other hand, strengthening of the vertical members at some levels may involve the rehabilitation of floors.

1.2. Rehabilitation Solutions for Horizontal Irregularities

In case of structural irregularities, the aim of rehabilitation is to reduce the eccentricity between the stiffness centre and mass centre: the result is a diminution of torsion effects and displacement as well as an increase of strength at lateral actions. The common solution is to use new, symmetrical walls.

For irregularities of the geometric plan, the rehabilitation solution consists in use of new walls and seismic joints.

1.3. Rehabilitation Solutions for General Structural Vulnerabilities

In case of indirect transfer of strong forces and horizontal members with large spans/high loads, the classical solution is to use additional columns (vertical or inclined) for transferring the strong forces to the existing (or new) foundations. For weak columns (in comparison to adjacent beams) their strengthening is necessary.

The rehabilitation solutions adopted in case of building components deterioration depend on the structural material.

Owing to structural vulnerabilities or/and torsion effects, elements of the system may be subjected to different displacements and some damages may result; special rehabilitation systems can be used: adding abutments in directions of low stiffness; building of additional Reinforced Concrete (RC) walls.

2. Specific Solutions for Rehabilitation

2.1. Reinforced Concrete Structures

RC structures are to be repaired and/or strengthened in cases when the general damage is limited, and demolished when the structural safety is greatly reduced and the rehabilitation cost is very high.

Repairs are used for surface deterioration, cracks, damage resulting from casting defects and reinforcement corrosion. The repair methods are: covering of damaged surfaces; filling of cracks with cement mortar, epoxy resin or other polymers; replacement or strengthening of damaged reinforcement.

Strengthening of RC structures takes into account the increase in strength, stiffness and ductility. In case of RC framed structures, the increase in stiffness and ductility is to be achieved by coating of beams, columns and joints. The coating is performed by reinforced concrete, steel profiles, carbon fibres, etc.

For RC frame-wall structures the increase of bearing capacity is achieved by coating the web, flange and coupling beam.

Sometimes it is necessary to transform the existing structure completely, especially for framed structures. In this case, special techniques are to be used namely;

a) steel bracing of RC framed structure;

b) filling of frame holes with reinforced masonry or reinforced concrete.

2.2. Masonry Structures

Masonry structures without reinforcement can be strengthened by:

a) erection of RC cores at appropriate distances, combined (if necessary) with straps at each level;

b) masonry lining with reinforced concrete;

c) masonry confinement with steel profiles;

d) masonry coating with CFRP systems;

e) interlocking of masonry walls at corners, crossings and ramification with RC elements and/or steel profiles;

f) adding new inner walls and/or some outside abutments.

3. Rehabilitation of Existing Structures

3.1. The "Palace" Building

The "Palace" structure (Fig. 1) is a huge building (underground floor, ground floor–restaurant, three storeys–apartments, timber roof), built before 1900's with a composite structure: masonry and RC framed structure (Fig. 2). Initially it was an entire masonry structure, but later the ground floor was changed: some resistance brick walls were cut and two longitudinal RC frames were erected to sustain all the vertical loads. Due to this architectural operation the structure became more vulnerable at seismic actions: by the transversal direction main part of the ground floor became unstable at horizontal actions because of some erected columns with hinge connection at both ends (masonry wall supports from the underground floor and first storey). Other vulnerabilities of the building consist of: overall lateral stiffness values along the two main axis are different; lack of seismic joints to divide building parts have different dynamic characteristics; lack of straps at each floor.

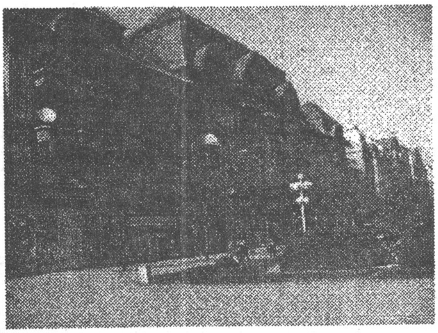

Fig. 1.– The "Palace" building.

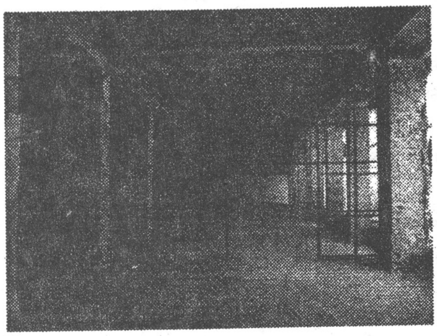

Fig. 2.– Longitudinal RC frames.

The building assessment emphasized some aspects: concrete quality is very variable in structural elements, having different classes (C8/10...C16/20); some cracks in longitudinal beams; corrosion of the slab reinforcement; etc.

The results of the static and dynamic analysis (performed by SAP2000N software) for columns are presented in Table 1 for non-rehabilitated and rehabilitated structure. Two assumptions were taken into account: vertical structural members are not coupled by floor elements over the ground floor; vertical members are coupled by the floor elements (rigid floor).

Table 1
Static and Dynamic Analysis Results for Non-Rehabilitated and Rehabilitated Structure

Type of structure	Analysis assumptions	Efforts		Transversal direction	Longitudinal direction
Non-rehabilitated structure	Not coupled structure	M, [kN.m]	M_{nec}	700	700
			M_{cap}	186	186
		$R = M_{cap}/M_{nec}$		0.27	0.27
	Coupled structure	M_{nec}, [kN.m]		127	700
		$R = M_{cap}/M_{nec}$		1.46	0.27
Rehabilitated structure	Not coupled structure	M, [kN.m]	M_{nec}	1,048	1,048
			M_{cap}	1,175	1,175
		$R = M_{cap}/M_{nec}$		1.12	1.12
	Coupled structure	M_{nec}, [kN.m]		473	1,048
		$R = M_{cap}/M_{nec}$		2.48	1.12

From data presented in Table 1 a very important conclusion could be drawn: the ratios, R, between the actual values of ultimate bending moment (M_{cap}) and the necessary bending moment (M_{nec}), given by the present-day seismic action level, were very low for columns, *i.e.* 0.27. That meant that the building was characterized by a high risk of collapse at seismic actions. It results the necessity of structural rehabilitation.

In accordance to the structural analysis, the strengthening of the ground floor was chosen in order to obtain technical and economical advantages: safe behaviour at seismic actions; slight change of the overall structural stifihess; easy strengthening technology and short period of refurbishment (December 2004 – June 2005).

The strengthening have been made on the following structural elements:

a) strengthening by RC coating (7 cm on each side) of masonry walls from the underground floor of the building;

b) new reinforced concrete floor with embedded steel profiles (HEB 220) in two directions, which stands as beams for the new structure (Fig. 3);

c) strengthening of half from the existing columns (60×60 cm coated by RC to become 90×90 cm – Fig. 3) and erecting of new transversal RC beams in order to create new transversal frames (Fig. 4);

d) strengthening by RC coating of existing longitudinal beams;

e) rehabilitation of some structural elements having corroded reinforcement as well as of some brick walls.

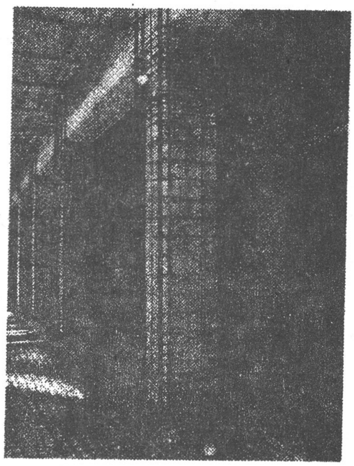

Fig. 3.– Strengthening of slab and columns.

The efficiency of strengthening solutions is shown by the increased R-values presented in Table 1.

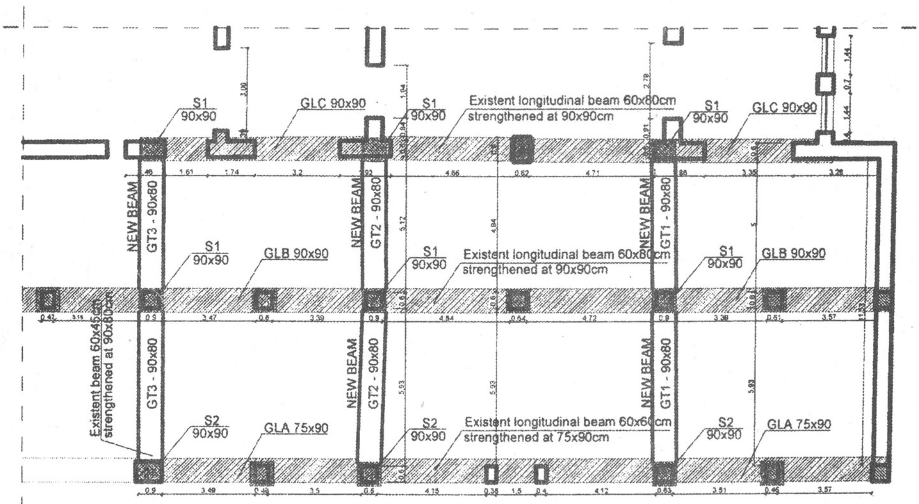

Fig. 4.– Ground floor rehabilitation.

3.2. Apartment House Affected by an Explosion

At the beginning of December 2002 an explosion was reported into a block of flats in the town of Timişoara, Romania (Fig. 5).

This building is five stories with 100 bed-sitters and the explosion was located in the second flat at the fourth floor. The cause of explosion was the leaking and accumulation of propane gas from a gas recipient into the flat. The initial explosion totally destroyed the concrete walls, reinforced concrete floors, windows and door of the flat and caused serious damage of the others structural members (Fig. 6).

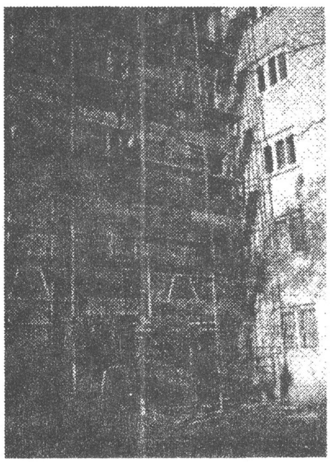

Fig. 5.– Block of flats.

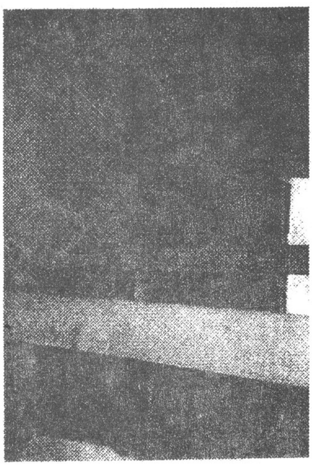

Fig. 6.– Fracture of RC walls.

The building is located in the periphery of Timişoara and was built in 1976. The building, in plane dimensions are 43.55×14.75 m and it has a sub-basement and five story of 2.72 m high. The structural composition of the building consists of: vertical structure built of longitudinal and transversal RC (over the borders) walls of 30 cm width for concrete façades and 15 cm of the interior walls; horizontal structure of 14 cm width precast RC floors.

From the structural analysis using FEM and the comparison between the explosion action and the possible seismic action according to the Romanian design code can be concluded that the explosion has no sensible effect on entire structure since only 20% of the horizontal seismic load in achieved; for six flats (three on each part of the gangway, surrounding the flat with the gas explosion) the horizontal load due to explosion represents 67% of the horizontal seismic load which is a source of structural elements damage.

The replacements and strengthening have been made on the following structural elements:

a) new RC floors, with the same geometry and reinforcement characteristics as for the existing members, at levels 3, 4 and 5, total five elements;

b) new RC walls at levels 4 an 5 which represent four transversal walls (with the same width as of the corresponding walls with new shirts) and four longitudinal-lateral walls;

c) local strengthening with RC shirt (5 cm on each side), columns (60×20 cm in the gangway and 30×20 cm at façade) and longitudinal beams at all levels (20×30 cm), vertical elements from ground floor to the roof, incorporating the new walls, on the one part of the gangway (Fig. 7);

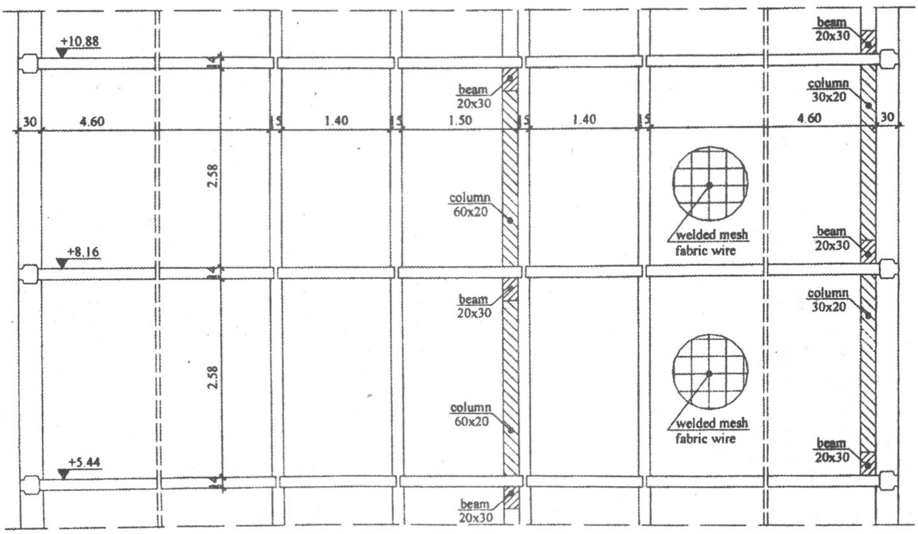

Fig. 7.- RC vertical rehabilitation solutions.

d) rehabilitation of the cracked elements with CFRP (Sika wrap) for 10 transversal walls and 12 floors (Fig. 8).

Fig. 8.– CFRP structural rehabilitation of walls and floors.

3.3. Masonry Buildings Affected by a Recent Earthquake

On the May 24^{th}, 2002, an earthquake of 4.6 degrees magnitude on Richter Scale was reported near the town of Moldova-Nouă located in the South-West part of Romania. The seismic motion, that was considered to have the local intensity of 7 degrees, affected many buildings. Among other buildings with important damages, two blocks of flats were evaluated and rehabilitated. The buildings have five stories and a sub-basement with in plane dimensions of 70.6×11.5 m. The structural composition of each building consists of: vertical structure built of transversal and longitudinal masonry walls of 30 cm for façades and 25 cm for interior walls; horizontal structure made of RC precast hollow strips, supported by transversal walls.

The main damages due to earthquake are: fracture of some precast strips of the floor over the sub-base; important damages of the longitudinal walls at the first floor; a lot of cracks on the longitudinal walls at 2^{nd} to 5^{th} floors; inclined cracks on the interior longitudinal wall; vertical cracks on the transversal walls near the joint with longitudinal walls; horizontal cracks on the transversal walls, at the first level, under the floor.

In accordance to the building damage assessment and structural analysis the strengthening has been made as follows (Fig. 9):

a) general strengthening of the perimeter walls with RC framed structures consisting of columns (20×40 cm) and beams (20×40 cm), which were connected with the existing structure by steel anchors;

b) new reinforced concrete slab (monolith, 6 cm thickness) over the existing precast strip at the first floor;

c) rehabilitation of the interior longitudinal wall using CFRP (Sika wrap).

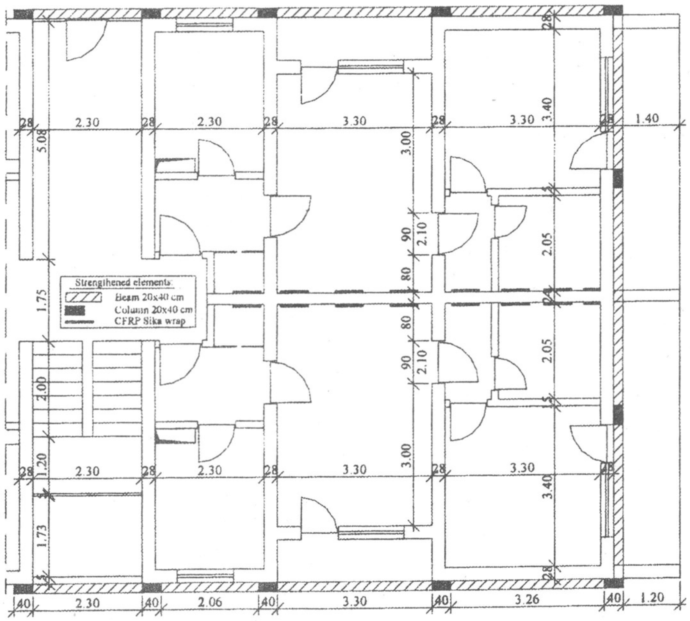

Fig. 9.– Vertical rehabilitation solutions for masonry building affected by earthquake.

4. Conclusions

The main ideas that emerge out from this study are summarized below:

1. The damages due to different extreme actions as earthquake, blast load, corrosion of reinforcement, etc., affected the structural resistance and stability as function of the load magnitude as well as of existing buildings vulnerability.

2. The analysis and design procedures of buildings subjected to extreme actions were adopted from those already used for existing structures in seismic zones.

3. The strengthening solutions have been selected in order to obtain technical and economical advantages: safe behaviour at seismic action; slight change of general structural stiffness; easy strengthening technology and short refurbishment period; low rehabilitation cost.

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REABILITAREA STRUCTURILOR EXISTENTE SUPUSE LA ACŢIUNI EXCEPŢIONALE

(Rezumat)

Se prezintă caracteristicile construcţiilor existente supuse la acţiuni excepţionale şi soluţii de reabilitare generale şi specifice structurilor din beton armat şi zidărie. Se descrie reabilitarea unor diferite tipuri de structuri existente: o structură în cadre din beton armat care prezintă vulnerabilităţi semnificative de alcătuire la acţiuni seismice; un bloc de apartamente avariat de o explozie de gaz; două clădiri din zidărie portantă afectate de un seism recent.