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SOME ASPECTS OF THE METHODOLOGY OF RESTORATION AND RENEWAL OF BUILDINGS DAMAGED IN THE 1976 FRIULI EARTHQUAKES

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SUMMARY

Some aspects of the methodology of restoration of buildings damaged in the 1976 Friuli earthquakes are looked into in the paper.

Those include some considerations relating to the ultimate conditions of masonry buildings strengthened against seismic action vis-a-vis a seismic coefficient K = = 0. 20.

Further illustration is provided of a technical form with the purpose of determining the cost parameters of renewal of buildings damaged by the earthquake.

1. FOREWORD

The 1976 Friuli Earthquake is marked by particular aspects owing to the simultaneous presence of a number of characteristic factors, which are:

a) The extension of the area affected (5,275 sq. Km. according the official statistics of the Friuli-Venezia Giulia Region, corresponding to 137 Municipal areas).

b) The number of inhabitants involved (approx. 590,000).

c) The fact that only 19 of the 137 Municipal areas were previously classified as seismic zones (2nd category).

d) The age and the typological building characteristics of the structures, in particular as regards the area destroyed or seriously damages (84 out of 137 Municipalities and an area of 3,431 sq. Km. out of 5,275).

An attempt will subsequently be made to specifically analyse some of the methodological characteristics for the restoration of the damaged buildings, with special reference to common housing in the area affected by the earthquake which, though it presents rather varied typological and construction characteristics, nevertheless offers a certain basic uniformity. This makes it possible to face certain problems (such as, for instance, a rapid estimation of restoration costs), with the certainty of obtaining satisfactory results.

2. TYPOLOGICAL CHARACTERISTICS

The number of housing units surveyed in the months immediately following the earthquake of 6 May which were considered suitable for restoration come to approx. 60,000 (in the case of about 9,000 the evaluation was found to be negative).
The average volume of the units is about 670 cu. met., with a minimum volume of 500 cu. met. in the case of buildings intended for housing accommodation alone; 890 cu. met. for buildings with auxiliary or annexed space intended for productive activity; and 1,080 cu. met. in the case of rural building with agricultural extensions (with a minimum of 300 cu. met. of accommodation in moutain areas and a maximum of 1,500 cu. met. of accommodation in the plains).

As regards buldings put up before 1900, the distribution aspects of the housing accommodation vary from area to area (in mountain zones one tends to find agricultural activity carried out on the ground floor, while the living area is usually upstairs; in the plains living space is also extended to the ground floor, with a general tendency to set up an annexe in line with the main unit, where agricultural activity is carried out).

The building materials are rather uniform, at least where their original composition is concerned (stone and wood), while the structural typology assumes particular aspects depending on the age of the structure and its geographical location.

In the case of buildings put up at a later date, the normal distributive and func tional characteristics of present day housing units - usually of the single-fam ily type - hold true.

Giventheir high incidence in the context of the problem being dealt with, partic ular attention will be given to housing accommodation structures as described above.

3. STRUCTURAL TYPOLOGY

As has been underlined, there does not exist a structural type that can be described by a single definition, in as much that the structures damaged by the 1976 earthquakes are to be found in areas with conspiscuous historical, cultural and economic differences.

However, a certain uniformity does exists, except in cases of structures of a more recent date and also of the more important edifices as regards the construction materials and their use.

Taking these common factors into account, buildings may be grouped together in satisfactorily uniform categories:

a) Isolated buildings

Having a regular plan, built of irregular stone and poor quality mortar, with a wooden flooring, varied wooden roofing.

In time may have undergone structural alterations, such as outer extensions and the replacement of parts of the flooring with reinforced concrete monolithic slabs or reinforced concrete and brick slabs.

b) Continuously-arrayed buildings

Put up in the interior of habitated centres, include various living quarters and present a continuous façade along the street.

Their plan may therefore turn out be rather intricate. Structurally they are made up of a ground floor, first floor, storehouse and wooden roofing. The bearing walls consist of two façades parallel to the street (supporting the roofing and generally the flooring of the storehouse) and of dividing walls,distanced at approx. 5 m at right angles to the street, which bear the first floor.

The materials are always wood and stone.

In this case too, modification of the original structure may be carried out by the putting up of a floor, the replacement of some of the floorings and the construction of additional structures perpendicular to the disposition of the array.

c) Recent buildings

Built in brick-work, flooring in reinforced concrete-brick slabs, in some cases the load-bearing structure in reinforced concrete. Generally based on irregular plan, often badly built and without particular reference to modern technological know-how.

d) As already noted, it should also be kept in mind that, notwithstanding the fact that the region is subject to high earthquake probability, only a small part was included in the 2nd category of seismic zones as per standing Italian Regulations. In this zone, which includes Tolmezzo, Verzegnis and a number of other Municipal districts which were subjected to a serious earthquake in 1928, structures built after this date according to the standing anti-seismic regulation of the period are to be found.

4. STRUCTURAL BEHAVIOUR

Taking into consideration the buildings of types a) and b), the bearing structure is made of non-squared stone masonry walls with low values of the aspect ratio, high specific gravity and rather low shear resistance.

The wooden floor is supported by wooden beams, resting on the walls.

The roofing is made up of roof - tree, trusses and common rafters resting directly on the wall or by means of wooden sleepers.

There are no ties, and practically never any joints between longitudinal and transversal walls.

The structural weight of the building is almost entirely made up of the weight of the walls and the overloading is practically negligible. In these conditions, lacking any bearing or connection whatsoever between the vertical elements, each element functions independently of the others, thus not being subject to torsional effects even in case of highly complex plans. In fact, the stiffness of the wall element may be shown as:

$$k_i = \frac{G_i \cdot A_i}{1.2\ h_i}$$

while its weight should be:

$$W_i = \gamma_i A_i h_i$$

Should all the elements be of the same material and of the same height, the weight of the flooring being negligible, the centre of rigidity coincides with the centre of the mass.

The situation changes when some structural elements are replaced with others of different material and with a greater values of the shear modulus and when the light flooring are replaced with reinforced concrete-brick slabs whose weight is no longer negligible and whose stiffness on their own plane is considerable.

Thus, the forces begin to be concentrated on the more rigid elements, while lightening the others; at the same time torsional effects arise.

As concerns the shear behaviour of the walls, spread cracks appear throughout their height, revealing in this way, in particular as regards the façade, the weakening caused by door and window openings.

It should be noted, moreover, that often the bearing walls are found to have been subjected to demolition and partial reconstruction, raising, openings for doors and windows, with a consequent modification of their static behaviour.

Further, given the almost complete absence of ties or tendons correctly placed, all the walls show gaps relative to those lying at right angles to them.

It may therefore be stated on the whole that all the buildings in the area affected by the 1976 earthquake, some of them dating back several centuries, were not build according to anti-seismic criteria.

The use of costlier materials and technology could not be afforded, except in the case of a few important structures, given the economic condition of the area.

The local artisan construction tradition appears to be lacking in skill even when compared to contemporary building standards.

The modification to the original masonry structures, carried out with materials and techniques borrowed from other types of constructions (it should be kept in mind that a part of local labour is employed in the building trade), not having been inserted appropriately in the structural concept of building, has in most cases worsened the existing situation.

5. METHODOLOGY OF RENEWAL

As has been mentioned previously, it is clear that structural renewal should aim at providing the structure with an acceptable degree of safety, while staying within certain economic and environmental criteria.

Concentrating on the safety criteria alone, the first step is to choose a masonry box as the resisting element.

The renewal to be carried on the frame consists in connecting the masonry walls in both directions.

Such connection may be made in various ways: by means of ties with double tendons so as to avoid eccentric compression in perimetral beams; by repairing the corners using steel mesh and concrete covering.

If the box made up of walls in stone and poor quality mortar, the shear factor has to be improved by injecting cement mix into the entire wall mass in order to achieve a satisfactory structural uniformity.

The reinforcement of the box may be effected in other ways, as for instance by strengthening the masonry with steel mesh or by introducing new dividing walls in solid brick or concrete.

For purposes of endowing the masonry with a certain solidity, wooden flooring is often replaced with a reinforced concrete hollow brick slab. From the structural view point this intervention represents a radical modification compared to the original scheme.

The box thus acquires its covering. It is obvious that the reinforced concrete-brick flooring operates as an efficient horizontal diaphragm which links together all the masonry it engages.

Torsional effects, which are lacking in the absence of the diaphragm, may therefore appear. Moreover, the presence of the new flooring, of a weight that is no longer negligible, may influence the behaviour of the foundation.

Correct planning should always aim at the coincidence of the centre of the mass with the centre of rigidity. Owing to this, if the masonry frame is in any way deficient, it is better to avoid the introduction of excessively stiff resistant elements which might unload , in an undesirable manner, the masonry having a shear modulus of low magnitude.

The consideration should be uniform over the entire range of elements so as to enable them to carry out their task of resisting horizontal forces but without concentrating on them dangerous stresses as regards the shear and the overturning moments.

Only if a correct co-operation of all the reinforced masonry is achieved, is it then possible to limit the safety verification of the building to shear resistance assessment.

Such testing should then be extended to all the floors and not only to the base of the building, in case variations are met with from floor to floor as regards resistance and the arrangement of the walls.

6. CALCULATION AND EVALUATION METHODS

The Italian norms laid out in the Ministerial Decree of 3/3/1975, which refer to the repair of masonry structures, do not contain adequate directions vis-a-vis planning aimed at the strengthening and safety of buildings in the context of seismic action.

To this end the Autonomous Region of Friuli-Venezia Giulia has issued, as an extension of the above-mentioned norms, recommendations that are the outcome of co-operation with various experts and organizations - both national and foreign.

Of particular importance among these recommendations is the test required for buildings that have been strengthened, with the purpose of assuming the behaviour of these structures in the presence of seismic action.

In brief, it is to be ascertained that the ratio VK between the horizontal forces bearing on the building in its ultimate conditions and the weight of the building is greater than a value $VK = C_1 \cdot C_2 \cdot 1.1 \cdot 0.2$ where C_1 and C_2 are values determined by the geomorphological nature of the ground, 1.1 is the safety coefficient and 0.2 is the seismic coefficient.

The verification may be carried out in one of many ways, but with the existence of the conditions cited above, it may simply be a verification on the average value of shear forces in the masonry.

In more complex cases, or as an aid to the project intended to optimize the arrangement of the strengthening elements, an iterative step by step method may be employed, which would locate the distribution of the shear forces on the various resisting elements, up to their yield point.

Given the particular constructional typology of the buildings, these two methods provide satisfactorily reliable results and, if correctly employed, can constitute an important step forward relative to the current Italian norms.

7. PARAMETRICAL EVALUATION OF RESTORATION COSTS

Besides the gradual development and the widening of the renewal methodology in the structural sector, it was also necessary to face the problem of a rapid evaluation of the costs of restoration. This was intended to facilitate the application of the first regional laws that touched the economic sphere, in order to accelerate to the utmost the renewal operations.

In this sense the authors, in their roles as consultants to the Regional Administration within the framework of the Central Interdisciplinary Group, have worked together to formulate a draft of the costs of renewal (tables 1 to 4).

The solution adopted made it possible, within a three-month period (that is, in the period enclosed by the first earthquake of 6 May 1976 and the second, that of 15 September), to survey and examine nearly 65,000 housing units, this being carried out with a maximum of 300 groups, each composed of 3 technicians.

Over and above an indication of the characteristics elements of the buildings, sub-divided into single housing units, the form puts forward in 4 tables parametric evaluation scheme of the repair costs, laid out thus:

a) The different constructional elements of the building (column 1) and the possible typologies of the elements themselves (column 2) are listed.

b) Column 3 shows the ratio in the ambit of each structural element, of the existence of different typologies (for example, if a building is made up of two bodies, of which one represents 60% of the volume with its bearing elements in stone and the other in hollow bricks, column 3 shows 0.6 which corresponds to the first type and 0.4 to the second).

c) The evaluation of the renewal cost is calculated on the basis of a volume index, according to the average parametric values (columns 5 and 8) relative to the various structural types. These costs (table 5) were determined (for example in case of buildings with bearing elements in stone, with wooden flooring) on the basis of the incidence of costs, for a typical structure, of a completely new construction and of total renewal and with reference to the overall volume of the building.
The cost of partial renewal was deduced from these (normally equal to 50% of total renewal) and column 5 and 8 were compiled beforehand.

The prices of course refer to May 1976.
In order to obtain the partial renewal cost, the value of column 3 is multiplied by the percentage of renewal considered necessary and also by the relevant unit cost, thus obtaining different partial costs, which then give the total renewal cost (with reference to the preceding example, if 50% of the stone masonry requires total renewal, 30% partial renewal, and no renewal for the rest. The relevant renewal cost is obtained as follows:

$$0.60 \cdot 0.50 \cdot 13,000 + 0.60 \cdot 0.30 \cdot 6,500 = \text{L/Cu. Met. } 5,070$$

relative to the overall volume of the building).

d) Column 10 sums together all the renewal costs relative to the single structural types and gives the final value.

Though presenting certain difficulties owing to different evalutation assessment, the system adopted drew complaints from only 5% - 6%, and it was possible to evaluate a total renewal cost of about 250 billion Lit. (approx $ 300 M.).

The total cost of the project was about Lit. 2.7 billion, corresponding to Lit. 33,000 per building, refering to the total number of structures surveyed (about 80,000) up to April, 1977.

From the point of view of efficiency and validity of the method, the following consideration may be drawn:

- For a particular type of building (for instance for buildins in stone bearing walls and wooden flooring) for which partial renewal is foreseen with an anti-seismic protection (whose cost was estimated around 4,000 - 5,000 Lit/Cu. Met.) a total cost index of about 23,000 Lit/Cu. Met. is obtained which with an increase of about 30% gives the present cost of about 30,000 Lit/Cu. met.

- On the basis of the first renewal plans (at present there are a further 30,000 buildings yet to be repaired) at current prices, it may be that the average renewal cost varies between 30,000 and 40,000 Lit/Cu. Met.. It is however necessary to take into consideration the fact that recent regional laws have permitted not only simple renewal of damaged buildings but also complete renewal with anti-seismic protection and the recovery of housing accommodation by means of works related to technical and distributive functionality, and this type of work normally involves an expense of 2,000 - 4,000 Lit/Cu. Met.

8. CONCLUSION

The widespread dimensions of the seismic action of 1976 in the Friuli region have raised various problems that may be considered to have been partly resolved, and which in part is the subject of further study and research.

From the operational point of view, the research for the restoration and renewal that assure anti-seismic protection of buildings - mainly for those with bearing masonry, and the adoption of evaluation methods of the related costs in a short period of time - these have aided in leading to a concrete start-up of the reconstruction stage, with its first phase consisting of repair of the damaged structures.

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REGIONE AUTONOMA
FRIULI-VENEZIA GIULIA

VERBALE DI ACCERTAMENTO
dei danni ad edifici per uso abitazione o misto

N. squadra ____ N. d'ordine ____

Foglio 1 Data ____

NOTIZIE RELATIVE ALL'EDIFICIO

Provincia ____ Comune ____ (riservato all'ufficio)

Frazione ____ Via ____ n. ____

Partita catastale ____ Foglio ____ n. mappale ____

Non accatastato ☐ Riferimento ____

1. Edificio composto da n. ____ piani fuori terra
2. Fronti comuni con altri edifici n. ____
3. Scantinato: totale ☐ parziale ☐ no ☐; sottotetto praticabile: no ☐ sì ☐
4. Alloggi n. ____
5. Abitazione rurale con annessi rustici: no ☐ sì ☐, n. ____
6. Attività produttive ubicate nell'edificio: no ☐ sì ☐, n. ____
7. Età presumibile dell'edificio: ante 1850 ☐ 1850-1920 ☐ 1920-1950 ☐ dopo 1950 ☐

GIUDIZIO SINTETICO SULL'EDIFICIO

8. Distrutto ☐
9. Non ripristinabile ☐
10. Ripristinabile: totalmente ☐ parzialmente ☐ Necessitano riparazioni strutturali? sì ☐ no ☐
11. Riparazioni già eseguite: in tutto ☐ in parte ☐
12. Non necessitano interventi ☐

CONTRIBUTO

13. Costo stimato delle opere di riparazione: . . . . lire ____
14. Spese per riparazioni già eseguite: . . . . lire ____
15. Totale . . . . lire ____ × 80% = lire ____

16. Alloggi n. ____ × lire 6.000.000 . . . . = lire ____
17. Abitaz. rurali con annessi rustici n. ____ × lire 10.000.000 = lire ____
18. Attività produttive n. ____ × lire 4.000.000 . . . . = lire ____
19. Totale . . . . lire ____

NOTE

Eventuali indicazioni su particolari motivi che consigliano la conservazione dell'edificio: ____

Altre osservazioni: ____

Firme dei componenti il gruppo di rilevamento	Firma del proprietario/i, dell'usufruttuario o dell'amministratore	Firma di convalida del sindaco
____	____	____
____	____	Data ____

REGIONE AUTONOMA
FRIULI-VENEZIA GIULIA

NOTIZIE SULL'UNITÀ IMMOBILIARE N. └─┴─┘

N. squadra	N. d'ordine

Foglio 2 ____________ Data____________________

NOTIZIE RELATIVE ALLE UNITÀ IMMOBILIARI COSTITUENTI L'EDIFICIO

Edificio di partita catastale n. └─┴─┴─┴─┴─┘ foglio └─┴─┘ n. mappale └─┴─┴─┴─┘ sub. └─┴─┘

ALLOGGIO O ABITAZIONE RURALE

1. Alloggio effettivamente e stabilmente occupato al 5.5.76:
   Totale stanze n. └─┴─┘ occupanti n. └─┴─┘ rilevati dal gruppo
   risultanti al Comune: occupanti n. └─┴─┘
2. Titolo di godimento dell'alloggio: proprietà ☐ affitto ☐
3. Alloggio non occupato effettivamente e stabilmente al 5.5.76:
   Totale stanze n. └─┴─┘
4. Motivo della non occupazione:
   alloggio abbandonato ☐ alloggio sfitto ☐ altro ☐ ____________________
   alloggio occupato solo per parte dell'anno perchè:
   seconda abitazione ☐
   occupanti emigrati ☐ altro ☐ ____________ ____________________

ANNESSI RUSTICI

5. Stalla ☐ m³ ______ 6. Fienile ☐ m³ ______ 7. Deposito attrezzi ☐ m³ ______

LOCALI PER ATTIVITÀ PRODUTTIVE

8. Laboratorio artigiano ☐ m³ ______ 9. Negozio ☐ m³ ______
10. Ufficio o studio professionale ☐ m³ ______ 11. Altro ☐ m³ ______

PROPRIETARIO/I O AMMINISTRATORE DELL'UNITÀ IMMOBILIARE

nome cognome data di nascita indirizzo (comune, via, n. civico)

1. ____
2. ____
3. ____

Firme dei componenti il gruppo di rilevamento	Firma del proprietario/i, dell'usufruttuario o dell'amministratore	Firma di convalida del sindaco
____________		
____________	____________	____________
____________	____________	
		Data____________

REGIONE AUTONOMA
FRIULI-VENEZIA GIULIA

N. squadra	N. d'ordine

Foglio 3 Data____________________

DETERMINAZIONE DEL VOLUME DELL'EDIFICIO

TIPOLOGIA			LATO (ml)	LATO (ml)	SUPERFICIE (m^2)	ALTEZZA (ml)	VOLUME (m^3)
1	2	3					
						TOTALE (m^3)	

STIMA SOMMARIA DELL' EDIFICIO AL 5/5/1976

TIPOLOGIA	STATO	VALORE UNIT. (lire)	COMPUTO DI STIMA		
			VOLUME (m^3)	TOTALE (lire)	TOTALE GENERALE (lire)
1 Edificio per abitazione civile	Ottimo	40.000			
	Buono	32.000			
	Mediocre	24.000			
	Cattivo	12.000			
2 Edificio per abitazione rurale	Ottimo	34.000			
	Buono	28.000			
	Mediocre	20.000			
	Cattivo	10.000			
3 Annessi rustici o attività produttive	Ottimo	20.000			
	Buono	16.000			
	Mediocre	10.000			
	Cattivo	6.000			

COMPUTO DEL COSTO DELLE OPERE DI RIPARAZIONE

TIPOLOGIA			
1	m^3 ______	× lire ______	= lire ______
2	m^3 ______	× lire ______	= lire ______
3	m^3 ______	× lire ______	= lire ______
			Totale lire ______

REGIONE AUTONOMA
FRIULI-VENEZIA GIULIA

EDIFICIO AD USO ABITAZIONE CIVILE, RURALE O MISTO

Tab. 4

N. squadra | N. d'ordine

Foglio 4 - A

Data__________

DETERMINAZIONE DEI COSTI DI INTERVENTO

ELEMENTO COSTRUTTIVO (1)		TIPOLOGIA (2)	PERCENT. SUL TOTALE (3)	RIFACIMENTO INTEGRALE % (4)	RIFACIMENTO INTEGRALE COSTO UNITARIO (L/m³) (5)	RIFACIMENTO INTEGRALE COSTO PARZIALE (L/m³) (6)	INTERVENTO PARZIALE % (7)	INTERVENTO PARZIALE COSTO UNITARIO (L/m³) (8)	INTERVENTO PARZIALE COSTO PARZIALE (L/m³) (9)	COSTO TOTALE INTERVENTO (L/m³) (10)
STRUTTURE VERTICALI		Murature in pietra			13.000			6.500		
		Murature in laterizio			11.000			5.500		
		Pilastri			3.800			1.900		
ORIZZONTAMENTI		Solai in legno, ferro e laterocemento			2.850			1.400		
		Solai in laterizio con travi in C.A.			5.200			2.600		
COPERTURA	STRUTTURA	Edifici fino a 2p. fuori terra			3.600			1.800		
		Edifici con più di 2p. fuori terra			2.100			1.050		
	MANTO	Edifici fino a 2p. fuori terra			1.150			600		
		Edifici con più di 2p. fuori terra			850			450		
SCALE					700			350		
TAMPONAMENTI ESTERNI					3.400			1.700		
TRAMEZZI		Edifici con muratura portante			200			100		
		Edifici con struttura in C.A.			1.000			500		
INTONACI E RIVESTIM. INTERNI					3.000			1.500		
INTONACI E RIVESTIM. ESTERNI					1.400			700		
PAVIMENTI					1.700			850		
INFISSI					3.000			1.500		
IMPIANTO IDROSANITARIO					1.500			750		
IMPIANTO TERMICO					4.000			2.000		
IMPIANTO ELETTRICO					1.000			500		
ALTRE OPERE										
ADEGUAMENTO ANTISISMICO										
TOTALE										

Edificio di abitazione in muratura portante in pietra
- n° 2 piani fuori terra
- Orizzontamenti in legno
- Volume 700 mc. vuoto per pieno

Elemento costruttivo	Costo unitario di costruzione		Costo di costruzione in £/mc. di fabbricato	Incidenze sul costo di costruzione del fabbricato	Costo di rifacimento integrale in £/mc. di fabbr.
Strutture verticali Murature portanti in pietra	£/mc	38.000	10.260	30,78%	13.000
Orizzontamenti Solai in legno	£/mq	10.000	2.285	6,85%	2.850
Struttura copertura in legno	£/mq	10.000	2.145	6,43%	3.600
Manto di copertura	£/mq	4.500	965	2,89%	1.150
Scale	A corpo	240.000	345	1,03%	700
Tramezzi	£/mq	3.500	150	0,45%	200
Intonaci interni	£/mq	3.400	2.770	8,32%	3.000
Intonaci esterni	£/mq	3.500	1.250	3,75%	1.400
Pavimenti	£/mq	7.000	1.490	4,48%	1.700
Infissi	£/mq	60.000	2.800	8,40%	3.000
Fondazioni	£/mc	40.000	860	2,58%	-
Vespaio e caldane	£/mq	4.500	515	1,54%	-
Finiture varie	-	-	1.000	3,00%	-
Impianto idro-sanit.	A corpo	-	1.500	4,50%	1.500
Impianto termico	A corpo	-	4.000	12,0%	4.000
Impianto elettrico	A corpo	-	1.000	3,00%	1.000
TOTALI	£/mc		33.335	100,00%	

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