EARTHQUAKES AS A SOCIAL PROBLEM

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The very fact that a conference dealing with the social, economic, and planning aspects of earthquakes is taking place indicates that it is considered that the residential and other buildings used by society for its activities existing today and perhaps still under construction are not safe against earthquakes.

The majority of countries which lie in regions where strong earthquakes may occur have their own codes concerning the construction of buildings in seismic regions. However, experience obtained from recent earthquakes since 1960, as well as the fact that intensive research is now going on in many countries of the world with the aim of providing seismically safe structures, indicates that the technical regulations of the past were not able, at least in sufficient measure, to assure the safety of buildings. This is the case even though these regulations are based on the principle that in the event of strong earthquakes serious damage may occur to buildings, but their collapse should be prevented.

The conclusions of the building group of the EEC, which met in Belgrade in April 1978 and dealt with problems concerning earthquakes, proposed that the regulations be amended with respect to the calculation of resistance and the estimation of the strength of an earthquake acting on a building. This indicates the unsuitability of the older regulations. The conclusions include the following passage: "Countries and regional organizations must make maximum efforts that for the design of structures in seismic regions the limit-state method of design be used. At the same time dates must be fixed by which time transition is to take place from calculations on the basis of permissible stresses to calculations on the basis of limit-state design." An additional conclusion was: "For determining the degree of intensity of earthquakes the MSK-64 scale should be used both in the preparation of seismic maps as well as when determining the extent of damage."

If account is not taken of the results of recent research, which has indicated solutions which would be in general economically acceptable, then it must be considered that "buildings of the past" will still abound--buildings which can neither be abandoned, nor strengthened. Thus the fact remains that for the foreseeable future strong earthquakes are still going to be natural catastrophies.

In relation to the conference subject matter, we should like to present:

- an estimate of the seismic resistance of residential brick masonry and stone masonry buildings, which we had the opportunity to determine in the earthquake-stricken regions of Yugoslavia, and
- an indication of the possibilities provided by mortar of higher quality and by horizontal reinforcement.

As our contribution to the conference we should like to present the experience we have acquired with repair work carried out in connection with earthquakes which have occurred in Yugoslavia over the last twenty years, and to present some general ideas concerning the approach to repair work.

An Estimate of the Seismic Resistance of Masonry Buildings

Definition and estimation of the seismic resistance of masonry buildings

The shear resistance of a masonry building is defined by the shear failure (collapse) of certain walls, which can be designated as the "relevant walls". Thus the relevant walls are those walls which determine the failure mechanism of the building. If it is borne in mind that the distribution of lateral load, as defined by the Base Shear Coefficient, onto individual walls (or groups of walls) is in proportion to their stiffnesses, then the relevant walls are those walls which are relatively the stiffest and of which there are a larger number. When the resistance of these walls, and their deformability (or "ductility"), is exhausted, failure occurs. The wall or whole group of walls loses its vertical-load carrying capacity, and collapse of the whole story occurs if there is no possibility for the transfer of the vertical load onto other vertical load-bearing elements.

The safety factor of a building for seismic loads thus depends on the safety factor of the relevant wall or group of walls:

$$V = \frac{\textcircled{1} \left[\text{The shear resistance of the relevant wall}\right] \quad \textcircled{3} \left[\text{The cross-sectional area of the walls orthogonal to the direction of the seismic shock}\right]}{\textcircled{2} \left[\text{The total inertial force acting in the story}\right] \quad \textcircled{4} \left[\text{The factor of increasing or decreasing of the load acting on the relevant walls}\right]}$$

If the elements of the above equation are expressed in mathematical symbols, then the parametric form of the condition of seismic resistance of the building is obtained (Figures 1, 2, 3):

$$\frac{I}{\Phi} = \frac{1}{n} \cdot n\,(\tau_k) \cdot n\,(\varphi) \cdot n\,(Z_h\,,\,Z_V) = 1$$

The resistance of the building, expressed by means of the Base Shear Coefficient, V.K., is obtained by iteration.

Estimate of the seismic resistance of brick masonry buildings

Pre-World War I buildings, built of "German format" bricks of dimensions 25x12x6 cm, as well as buildings built of modular brick blocks of dimensions 30x20x20 cm, have been taken into consideration as widespread typical brick masonry buildings. Table 1 shows calculations for ceramic blocks and high quality mortar, and as an alternative the same walls reinforced with horizontally placed stirrups.

a. Analysis of existing brick masonry buildings (Rows 1, 2, and 3 in Table 1)

An insight into the seismic resistance of existing brick masonry buildings has been made possible by parametric analysis, the wall element tests so far carried out in the laboratory, surveys of wall layouts of actual buildings (though for only a smaller number of buildings) and an estimate of the method of construction used.

The influence of the parameter of wall layout on seismic resistance can be seen from the table in Figure 3. The value of this parameter $n(Z_h, Z_y)$ can fall from an ideal value of 100% to a very small percent. Such is the case with the so-called "tunnel construction", where all the load-bearing walls are oriented in one direction. Such buildings are demolished by an earthquake shock acting at right angles to the plane of the walls, as examples at Skopje have shown. The fashion of tunnel construction (in reinforced concrete construction, too), as well as complicated, unsymmetrical wall layout plans which cause torsional loadings, results in the inclusion of a certain number of seismically unstable masonry buildings among our existing buildings.

In the analysis presented in Table 1, relatively favorable wall layout plans have been assumed, as is the case with a large number of older buildings. From Table 1 the influence of wall thickness, which in the case of older buildings increased with increasing building height, can be seen. In the ground floor wall thickness was a minimum of 45 cm before World War I, after 1930 it was 38 cm, and after 1960, when modular measurements were introduced, 30 cm, at which time the requirement that cement-lime mortar be used for the construction of masonry buildings in seismic regions was also introduced into the technical regulations.

In the first row of Table 1 the suburban dwelling houses owned by moderate income inhabitants have been analyzed. These are mainly single story buildings with an occupied attic and walls not tied together at ground-floor ceiling level. In the Skopje and Banja Luka earthquakes failure of such buildings built of poor quality bricks and mortar occurred, consequently statistics of failures and damage indicated the false generalization that "brick masonry is not a suitable building material for seismic regions".

The safety factor of a building depends on the safety factor of one of the relevant walls. As the relevant walls are denoted those walls which define the failure mechanism of the building, according to their relatively greater stiffness and larger number.

$$V = \frac{① \left[\begin{array}{l}\text{The resistance of the}\\ \text{revelant wall}\end{array}\right] \cdot ③ \left[\begin{array}{l}\text{The cross-sectional area of}\\ \text{the walls standing in the}\\ \text{direction of the seismic force}\end{array}\right]}{② \left[\begin{array}{l}\text{The total inertial force}\\ \text{acting in the story}\end{array}\right] \cdot ④ \left[\begin{array}{l}\text{The factor of increasing or}\\ \text{decreasing of the load acting}\\ \text{on the relevant wall}\end{array}\right]}$$

Substituting for the expressions in the above equation with the parameters and symbols listed in the appendix, the following equation for V can be obtained:

$$\text{(1)} \qquad V = \frac{① \left[\tau_k \sqrt{1 + \frac{\sigma_{or}}{\sigma_n}}\right] \cdot ③ \left[\phi F_{tot} \ \lambda_h\right]}{② \left[K \ \phi \ F_{tot} \ n \ \gamma \ h \left(1 + \frac{q}{\gamma \ h \ \phi}\right)\right] \cdot ④ \ [\omega]}$$

The vertical bearing stress in the relevant wall σ_{or} can be expressed as follows:

$$\text{(2)} \qquad \sigma_{or} = \gamma \ h \ n + \frac{q \ F_{tot} \ n \ f}{\phi \ F_{tot} \ \lambda_h}$$

Substituting this expression into Eq. (1) we obtain:

$$\text{(3)} \qquad V = \left(\frac{1}{K \ n}\right) \left(\frac{\tau_k}{\gamma \ h}\right) \left(\frac{\lambda_h}{\omega}\right) \left(\frac{1}{1 + \frac{q}{\gamma \ h \ \phi}}\right) \cdot \sqrt{1 + \frac{\gamma \ h \ n}{1.5 \ \tau_k}\left(1 + \frac{q \ f}{\gamma h \phi \ \lambda_n}\right)}$$

If Eq. (3) is squared and solved for the number of stories n, then the following expression is obtained:

$$\text{(4)} \qquad n = \frac{1}{3 \ V^2 \ K^2} \cdot n \ (\tau_k) \cdot n \ (\phi) \cdot \left\{Z_h^2 \cdot Z_v \left(1 + \sqrt{1 + \frac{9 \ V^2 \ K^2}{Z_h^2 \ Z_v}}\right)\right\}$$

Figure 1

Parametric Analysis of the Seismic Resistance

h_l - height of the wall,

d_l - length of the wall,

G - shear modulus of the wall,

D - deformability modulus of the wall,

F^* - cross-sectional area of the wall,

F^*_{tot} - total cross-sectional area of walls in the story,

q - weight of the floor structure (dead load + live load),

γ - volumetric weight of the wall,

n - number of stories,

φ - ratio of the cross-sectional area of the walls supporting the floor structures to the net-area of the story

f - part of the floor structure area which is supported by the walls standing in the direction of the seismic force

F_{tot} - net-area of the story,

λ_h - ratio of the cross-sectional area of the walls standing in the direction of the seismic force to the total cross-sectional area of walls in story,

λ_p - ratio of the cross-sectional area of the walls standing perpendicular to the direction of the seismic force to the total cross-sectional area of the walls in the story,

λ_v - ratio of the cross-sectional area of the walls supporting the floor structures and standing in the direction of the seismic force to the total cross-sectional area of the walls in the story,

ω - correction factor for the distribution of the total seismic force to individual walls,

s.m. - coefficient of increase of resistance due to additional structural measure, obtained from laboratory tests.

$$n(\tau_k) = \frac{\tau_k}{\gamma h}$$

..........function of the equality of the walls.

$$n(\varphi) = \frac{1}{1 + \frac{q}{\gamma h \varphi}}$$

..........function of the parameter of the ratio of the area of bearing walls to the net-area of the story.

$$\frac{1}{n}$$

..........function of the number of stories.

$$Z_h = \frac{\lambda_h}{\omega}$$

..........parameter of the distribution of the total seismic force onto the walls standing in the direction of the seismic force.

$$Z_v = \frac{1 + \frac{q}{\gamma h \varphi} \cdot \frac{f}{\lambda_v}}{1 + \frac{q}{\gamma h \varphi}}$$

..........parameter of the distribution of vertical load onto the walls standing in the direction of the seismic force.

$$\phi = \frac{12\, V^2\, K^2}{1 + \sqrt{1 + 36V^2K^2}}$$

..........function of seismic load given with the seismic coefficient K and safety factor V (base shear coefficient at failure).

$$VK = \phi \sqrt{\frac{1}{6\phi} + \frac{1}{4}}$$

$$n(Z_h\, Z_v) = \frac{Z_h^2\, Z_v}{0{\cdot}25} \cdot \frac{1 + \sqrt{1 + \frac{9V^2K^2}{Z_h^2\, Z_v}}}{1 + \sqrt{1 + 36V^2K^2}}$$

.......function of the structural layout of the building.

$$n(s.m) = (s.m)^2 \cdot \frac{1 + \sqrt{1 + \frac{9V^2\, K^2}{Z_h^2\, Z_v^2\, (s.m)^2}}}{1 + \sqrt{1 + \frac{9V^2\, K^2}{Z_h^2\, Z_v^2}}}$$

....function of parameter of structural measure

Figure 2

List of Symbols and Formulas

CONDITION OF STABILITY: $\frac{1}{\Phi} \cdot \frac{1}{n} \cdot n(\varphi) \cdot n(\tau_k) \cdot n(Z_h \cdot Z_v) = 1$

$$n(\varphi) = \frac{1}{1 + \frac{q}{\gamma h \varphi}} \quad ; \quad \gamma h = 5 Mp/m^2$$

q \ φ	0.06	0.08	0.10	0.15	0.20	0.30	0.40
0.400	.43	.50	.56	.65	.71	.79	.83
0.500	.38	.44	.50	.60	.67	.75	.80
0.600	.33	.40	.45	.56	.63	.71	.77
0.700	.30	.36	.42	.52	.58	.68	.74

$$n(\tau_k) = \frac{\tau_k}{\gamma h} \quad ; \quad \gamma h = 5 Mp/m^2$$

τ_k	1.0	1.5	2	5	10	15	20	25	Mp/m^2
$n(\tau_k)$	.20	.30	.40	1	2	3	4	5	/

$$n(Z_h \cdot Z_v) = \frac{Z_h^2 \cdot Z_v}{0.25} \cdot \frac{1 + \sqrt{1 + \frac{9V^2 \cdot K^2}{Z_h^2 \cdot Z_v^2}}}{1 + \sqrt{1 + 36V^2K^2}} \quad ;$$

$$Z_h = \lambda_h \quad ; \quad Z_v = \frac{1 + \frac{q}{\gamma h \varphi} \cdot \frac{f}{\lambda_v}}{1 + \frac{q}{\gamma h \varphi}}$$

Z_v \ Z_h	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10
1	1.00	.83	.68	.54	.42	.31	.23	.15	.11
0.80	.85	.70	.58	.47	.37	.28	.21	.14	.10
0.60	.70	.60	.50	.41	.33	.25	.19	.13	.09
0.40	.57	.49	.42	.35	.28	.23	.17	.12	.08

Figure 3

Values of the Coefficients of the Parametric Functions

Table 1

Calculation of the Seismic Resistance of Existing Brick Masonry Buildings, Assuming Favorable Wall Lay-outs

No.	Type of building (γ = 1.8 Mp/m^3)	Wall quality			Walls of building					Building resistance given by Base Shear Coef.					Corresp. earthquake intens. on MSK scale
		σ_n(exp.)	τ_k	n (τ_k)	Thick-ness in cm.	φ	n(φ)	Z_h	Z_v	No. of stories (n)					
		kp/cm^2	kp/cm^2							1	2	3	4	5	
1.	Suburban buildings of lowest quality. Buildings usually not tied. h = 3.5 m	0.4	.25	.50	25	.08	.44	.30	.70	.11	.07	-	-	-	VII
2.	Pre-WW II buildings, built of solid bricks ("German format") in good lime mortar h = 3.5 m	1.0	.55	.87	38 51 64	.13 .17 .21	.62 .68 .73	.40	.80		.19	.15	.13	.12	VIII
3.	Buildings built of modular brick blocks in cement-lime-sand mortar h = 2.8 m	1.8	1.0	2.00	30	.10	.50	.30	.70		.21	.15	.13	.11	VIII
4a.	Buildings with high-quality brick walls, using mortar of quality β_m = 150 - 200 kp/cm^2 h = 2.8 m	3.5	1.9	3.8	20	.08	.44	.40	.70		.42	.30	.24	.21	IX
4b.	As in 4a, with horizontal steel reinforcement ϕ 6 mm	As in 4a + (s.m.) = 1.35										.41	.33	.28	IX

It also follows from Table 1 that carefully designed and built older masonry buildings built of solid bricks, but using lime-sand mortar, as well as newer buildings built using modular brick blocks and the required cement-lime mortar, can withstand earthquake shocks of intensity VIII on the MSK-64 scale.

b. Brick masonry prospects in view of new thermoinsulation requirements (Rows 4a and 4b in Table 1)

The trend towards the greater competitiveness of brick construction for residential buildings has resulted in the building of brick walls out of modular brick blocks with a thickness of 30 cm in the ground floor. The reduced thermoinsulation due to the reduced thickness of such walls has been partly compensated for by perforating the blocks. However, much greater thermoinsulation is required by today's energy crisis, which is not possible to obtain by increasing wall thickness, and so it would appear on the face of it that the great advantage of brick has been lost.

A step forward could be taken by reducing the thickness of brick bearing walls to 20 or 25 cm and simultaneously adding a layer of thermoinsulation. In this case another problem arises, that of providing sufficient load-carrying capacity, and, in particular, seismic resistance. The results of tests carried out on some walls have shown that by the use of high-quality mortar it is possible to increase substantially the shear resistance of brick walls. The analysis shown in Table 1 indicates in general a substantial increase in the seismic resistance of buildings in comparison with the method of construction so far used, so that in all cases resistance to earthquakes of intensity IX is achieved.

The supposed drawback of using mortar with a compressive strength of over 100 kp/cm^2 is that walls built using such a mortar would be brittle, i.e. without ductility. Proof that this is not the case follows from the measured values of the deformational characteristics of walls of groups II, III, V and VI, as is shown in Table 2.

Estimate of the seismic resistance of stone masonry buildings

In Yugoslavia most stone masonry buildings are in the countryside. Stone was used as almost the exclusive building material up to the end of the last century.

In cities and urban areas, stone masonry buildings represent ethnological, cultural and historical monuments of extreme value, which must be preserved in the future.

The resistance of such buildings to seismic forces, defined by the shear strength of a stone masonry wall is sometimes extremely low. Fortunately, the resistance can be substantially increased by means of cement injections. Taking into account other favorable characteristics of stone masonry buildings--greater thickness of walls, favorable structural layout--the cement injections represent a cheap solution during revitalization when the seismic resistance of buildings must be improved, which does not require additional structural elements and does not change the building aesthetically.

The constructional characteristics of stone masonry walls of various categories, as determined during the test, were as follows:

Cat. I. Two-faced stone walls whose cavities are filled with poor quality lime mortar made of clayey sand and earth. These walls were unplastered. The walls of old dwellings in the Kozjansko, Soča Valley and Friuli regions are of this type.

Table 2

Estimated Seismic Resistance of Stone Masonry Buildings

	Tensile strength σ_n	Shear modulus G	Ductility δ_{max}/δ_0
	kp/cm^2	Mp/cm^2	-
Walls of group II	1.7	4.3	3.2
" " " III	2.6	4.0	3.9
" " " V	4.7	9.4	3.4
" " " VI	3.0	4.7	3.3

Cat. II. Two-faced walls built of quarried stone whose cavities are filled with stone fragments and lime-mortar containing clean sand as aggregate. These walls are unplastered. The dwellings of the Montenegran Littoral are built with such walls.

Cat. III. Two-faced walls built of roughly-hewn quarried stone, whose cavities are filled with stone fragments and lime-mortar containing clean sand as aggregate. These walls were plastered using cement-lime-sand mortar. The public buildings (schools) of the Montenegran Littoral are built with such walls.

Cat. IV. Two-faced walls built of quarried stone (A,B) and of rounded riverbed stone (C,D), both filled with stone fragments, plastered and grouted. As was seen from the surfaces where fractures occurred, the larger part of the grout mixture was taken up by the inner part of the wall, which had thus turned into good, "prepacked" concrete.

In Table 3 the calculations for buildings with basic and cement-grouted walls have been presented.

Experience and Suggestions in Connection with Repair Work

After the occurrence of an earthquake the most urgent task is providing aid to the survivors: rescuing people from under the wreckage, supplying medical aid to the injured, and arranging emergency shelter and medical protection, and other similar measures. However, soon questions arise as to what should be done with the damaged buildings.

These questions are not only of a technical nature, but can also be primarily of a socio-political nature, and it is to them that particular attention has been paid in this contribution.

Decisions to demolish or repair

Already during clearing up operations after an earthquake, i.e. the removal of wreckage and the demolition of badly-damaged buildings, strictly political questions can arise. This was the case in the Slovene ethnic region in Friuli, where the population, with the support of Italian progressive intellectual and political forces in Friuli, put up physical resistance to demolition work, which had been taken on by various enterprises and organizations completely from a profit-making point of view.

On the first inspection of buildings, when the removal of wreckage is to take place, the rule should be followed that the demolition should take place of only those buildings or parts of buildings which threaten the safety of passersby. Otherwise the final decision of whether or not a building should be demolished should be delayed until a damage assessment has been made, or until proposals for repair and strengthening have been made. In any case it should be delayed sufficiently so that the user of the building can make a conscious and free decision.

Damage assessment principles

When assessing damage it is not appropriate to use as a basis the insurance practice by means of which the value of the building when new is assessed and then depreciated over the period of its existence. If such a method were used, in the case of old buildings absurdly low values would be obtained, particularly in economically backward areas.

The only estimate of damage caused by an earthquake which is really appropriate is the restitutional value. This represents the financial means which will be needed to restore to the buildings their full usable value. This means that in the case of a future earthquake whose strength has been estimated a residential building must be safe, which means that it may be damaged but must not collapse.

If it is not expected that an earthquake will occur in the future with a greater intensity than the one which has already occurred, and if

Table 3

Influence of the Quality of Different Types of Stone Masonry Buildings and the Effect of Grouting on Seismic Resistance Given by the Base Shear Coefficient and Calculated by Parametric Analysis

$$n(\varphi) = \frac{1}{1 + \frac{q}{\gamma h \varphi}} \quad ; \quad n(\tau_k) = \frac{\tau_k}{\gamma h} \quad ; \quad \gamma = 2100 \text{ kg/m}^3$$

TYPE OF BUILDING	AMOUNT OF WALLS	QUALITY OF WALL		WALL LAYOUT		BASE SHEAR COEFFICIENT						EFFECT OF GROUTING
		basic τ_k Mp/m^2	grouted τ_k Mp/m^2	Z_h	Z_v	BASIC WALL			GROUTED WALL			
						STORIES			STORIES			
	n(φ)	n(τ_k)	n(τ_k)			1	2	3	1	2	3	
A. STONE-MASONRY DWELLINGS WALLS OF CATEG. I $q = 0.40$ Mp/m^2 $h = 3$m	0.30 0.83	1.5 0.24	8 1.27	0.45 0.35	0.85	0.18 0.14	0.12 0.09	0.09 0.07	0.59 0.46	0.34 0.27	0.26 0.20	3
B. STONE-MASONRY DWELLINGS WALLS OF CATEG. II. $q = 0.40$ Mp/m^2 $h = 3$m	0.30 0.83	2 0.32	10 1.6	0.45 0.35	0.85	0.21 0.16	0.14 0.11	0.11 0.08	0.71 0.56	0.41 0.32	0.30 0.23	3
C. STONE-MASONRY PUBLIC BUILDINGS WALLS OF CATEG. III. $q = 0.50$ Mp/m^2 $h = 4$m	0.20 0.77	5 0.60	12 1.4	0.45	0.80		0.19	0.15		0.34	0.25	1.7
D. STONE-MASONRY BUILDINGS. WALLS OF CATEG. IV. (CRAD) PREPACKED CONCRETE $q = 0.50$ Mp/m^2 $h = 4$m	0.20 0.77		23 2.7	0.45	0.80					0.58	0.41	2.9 based on ungrouted wall cat. III.
ESTIMATE OF EARTHQUAKE DEGREE:						VII., VIII.			IX.			

a building has not been damaged to such an extent as to indicate that the building had started to collapse, then it is sufficient if the resistance of the damaged elements is restored to its original level.

Categorization of damaged buildings

An assessment of the extent and degree of damage should be obtained by means of damage categorization. A categorization scheme can be prepared by the group of experts who have inspected the earthquake-stricken region. The categories consist of: I) practically undamaged buildings, II) buildings with damage to non-structural elements (footings, chimneys, partition walls), III) buildings with damage to the vertical load-bearing elements:

a) with less serious but defined damage and
b) with more serious but also defined damage to the vertical and horizontal load-bearing elements,

and IV) buildings to be demolished with reasons given. This work, which includes obtaining data on the number of stories and the floor area, should be carried out by one group. If the damage assessment work is to be distributed among several groups, care has to be taken that a uniform coordinated approach to this work is followed. Categorization is carried out by inspecting each building individually. If mistakes are made during categorization it is always possible to correct them when repair work is started. However, categorization is the basis for the assessment of damage, its extent, and the distribution of seismic intensity over the earthquake-stricken region.

Financial evaluation of damage

A financial evaluation of the damage caused by an earthquake can be obtained by means of characteristic examples of the larger number of buildings in each category. The actual restitutional value for a building in any particular category is obtained on the basis of a uniform specification of work, which is prepared by a group of experts, taking into account calculated prices prepared by independent quantity estimators.

The other method of financial evaluation of damage consists of the use of a damage assessment questionnaire, which includes all possible repair work, and into which the necessary quantities are entered in physical units. Prices are, as before, calculated by several quantity estimators, and after coordination and final acceptance of the uniform prices the quantities obtained for individual buildings are multiplied with this uniform price, so that the restitutional value of an individual building is obtained.

We have used both methods in practice in the past. The second method can be used if only a small number of buildings are involved. However such a price provides no substitute for the actual restitutional value which is obtained when the repair plans are completed and other data about the quality of materials and other conditions of construction are obtained. The computer print out should certainly not be used as a document proving the right to assistance or loans. It should be considered only as an element of calculation, which is what this method of estimation really provides.

The financial estimate of damage, with documentation concerning the completed categorization of damage as well as documentation about the characteristic buildings on the basis of which the calculation of restitutional costs was made, is a document by means of which applications for solidarity assistance and its distribution to the various locations of the earthquake-stricken region can be justified. It must be carefully stored for future reference.

If the restitutional value is used as the basis for damage assessment, and repair work is carried out on this basis, then it is evident that the earthquake-stricken region will, particularly if it was a less-developed one where the largest damage usually occurs, make considerable progress in its development after the repair work has been carried out. As residential living conditions will essentially improve, this will create an improvement in economic conditions, too. This is logical, as investments in the standard of living result in an increase in the region's social productivity.

The programming and design of repair work

In principle, when carrying out damage assessment the method by which a building is to be repaired should be determined. So far this has not been so in the majority of cases. On the other hand rebuilding and replacement work, which was considered when making damage assessments, did not represent lower costs than the proposed methods of repair based on laboratory tests and repair work carried out on this basis. In our opinion, in all cases laboratory tests of repairs to load-bearing elements should be included in the designs and calculations of repaired buildings. These tests indicate the existing quality of the elements, which provides an estimate of the intensity of the earthquake, and also the increase in resistance which is obtained by using a chosen method of repair. Thus by means of laboratory tests of elements the intensity of the earthquake can be estimated from actual buildings, as well as the effect achieved by the repair work. This also forms the basis for an assessment of the correctness of the design.

The carrying out of repair work

For the repair and simultaneous strengthening of stone masonry walls it has been shown by lab tests that cement grouting is very satisfactory. However, there has been considerable resistance to cement grouting from those who were starting to carry out repair work, as for instance in the Soča Valley Region, where youth groups with local technical leaders with the necessary experience were employed. When carrying out repair work in regions where individual buildings are very scattered such resistance is understandable, as larger building enterprises cannot take on such work, but nevertheless the necessity of cement grouting should be insisted upon and teams capable of carrying out this work should be organized. In Friuli, where two successive strong earthquakes occurred, the experience obtained with respect to the effectiveness of methods of repair was the same as that obtained in the Soča Valley Region. The conclusions were formulated in the publication of Assessorato dei Lavori Pubblici 1976, Regione Autonoma Friuli-Venezia Giulia, which read as follows: "More than clear proof of this was provided by the behavior of already repaired buildings in the following September earthquake. Whereas superficial repairs and those unaccompanied by antiseismic strengthening frequently failed and caused the irreparable destruction of buildings, those in which repair work had been carried out technically correctly performed satisfactorily and protected buildings from repeated heavy damage."

When carrying out repair work using methods which are not yet well-known in individual regions, and in those cases in which the repair work will not be carried out by larger building enterprises, it is recommended that demonstration building sites and training be organized for working groups which will carry out the repair work.