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DEVELOPING THE MACROSEISMIC SCALE OF NEW GENERATION

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ABSTRACT

Drawbacks and improvement of the existing earthquake-intensity (macroseismic) scale MM/MSK/EMS-98 are under consideration. The suggestions on introducing the new improved IMSK (improved MSK) macroseismic scale of the earthquake intensity in exchange for the aborted "Macroseismic scale with intensity of 6-9" (National standard 6349-52) and the MSK-64 scale are set forth. The drawbacks and advantages of the previous scales, including EMS-98, are analyzed. The concrete approaches and decisions on improving the scale are offered. Of especial importance is the estimation and use of the classified structural vulnerability of standard objects of impact and response (OBIR) when assigning the intensity. Defined relations between damage grade and intensity degree and scale of serviceability limit states are given.

Introduction

An obligatory and a very important tool for assessment and analysis of the historical, recent and expected earthquakes is the unified measure of manifestation and impact of one or another earthquake on the bio- and techno-environment. This measure is expressed through the sensation and reaction of the representatives of the animate nature (people, animals) and inanimate objects (mainly of the built environment). This measure was called a force or intensity of the earthquake and the first scale of intensity was accepted by Rossi (Rossi – Forel) in 1878.

From time to time there appeared and were used a lot of other suggestions (Omori, 1900; Merkalli, 1902; their modifications in 1920, 1932, 1950). But the tendency to create the most accurate and unified scale became much stronger in the second half of the XX century.

The most progressive and popular scale in 50s – 80s was the MSK scale offered by S.V. Medvedev (USSR, Moscow) together with U. Schponher (GDR, Iena) and V. Karnik (ChSSR, Praga). Of common knowledge are the modernized variant of this scale – MMSK and other suggestions made by S.V. Medvedev, N.V. Shebalin and other scientists from the Institute of Earth Interior Physics (Moscow).

More than 50 years have passed since the "Macroseismic scale with intensity of 6-9" (GOST 6349-52, 1993) was introduced in the former USSR. This National Standard adopted in the USSR wasn't altered and later was cancelled without any replacement.

Unfortunately, the initiative role of the Russian scientists in developing the scale was lost in 90s. Owing to the work of the group of the European Seismologic Commission under the leadership of G. Grüntal

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(Germany, Potsdam), by 1993 there had been prepared and published the draft of the EMS-92 scale which was translated into Russian by M. Klyachko and edited in a small edition in January 1996. In 1998 the European Seismologic Commission adopted the unified macroseismic scale EMS-98 as a fundamentally modernized MSK scale but the instrumental part of the scale was not developed because the opinion on the necessity and possibility to create and to use this part of the scale for assigning the intensity was not common.

Meanwhile, in Russia, there was prepared a draft of the MMSK scale. Later F. Aptikaev suggested a new instrumental scale of intensity (Aptikaev, 2000), and the author (Klyatchko, 2000b) proposed a new unified Improved MSK macroseismic scale (IMSK) instead of National Standard –GOST 6349-52. The joint suggestion of these authors were reported, discussed and approved at the meeting of Russian Interdepartmental commission on seismic zonation and earthquake engineering in 2001.

The absence of the officially accepted unified international standard of the seismic intensity scale hampers in development of the engineering seismology, prevents the improvement of mutual understanding and joint work of seismologists and engineers, making the understanding of seismic risk and providing the seismic safety difficult. Along with Seismic Code the scale is the obligatory document in the seismic safety field and intended, first of all, for the assessment and analysis of the consequences of earthquakes which have already occurred.

In autumn 2002, the author and F. Aptikaev drew up a questionnaire on the new scale of the seismic intensity and sent it out to many specialists in Russia and other countries in Central Asia, Caucasus and Eastern Europe (46 responses from Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Tadjikistan, Ukrain and Uzbekistan). The answers received are evidence of the sharp need in the scale standard and show that the sight of the scale given below is supported by the specialists.

The approaches and suggestions given below are linked harmoniously with theoretical and practical aspects which the author has been using and developing for last 20 years for the analysis and management of seismic vulnerability and risk (Klyatchko, 1987, 1994a,b,c, 1995, 1996a,b, 2000a,b, 2002a,b, 2003).

The Main Features of the IMSK Scale

General Approaches and Solutions

The main criteria of the new IMSK scale (Klyatchko, 2000b, 2003) are to be the following:
- consistency and rational adequacy;
- continuity;
- operational reliability;
- simplicity, accuracy and unambiguous use.

The scale is supposed to be traditionally subdivided into 12 grades where the intensity (European Macroseismic Scale, 1992) is expressed by the integers only. It does not mean that seismologists and geologists cannot use any fractions as the working interim values of intensity, but the intensity is to be expressed by the integers only, the working values being 8 - from 3 to 10 inclusive. The intensities of 1 and 2 are barely noticeable and of a little interest. Intensities of 11 and 12 are very rare; we know a little about them and the reaction of majority of structures to such earthquakes does not differ from I = 10 that means the complete or partial (that happens rarer) collapse.

The intensity being assigned is supposed to be not point wise but the integral value for the urban territory which is not very large and not very multifarious.

An important condition of the scale is a refusal to regard the soil and demographic factors when assigning the intensity value. It is the condition that gives the possibility for further analysis of these factors of risk.

It is planned to eliminate some drawbacks of the previous scales in the IMSK scale. Some drawbacks eliminated and improvements suggested are described below.

IMSK must have a larger engineering essence than the previous intensity scales. It is mainly provided by introducing the definition and generalized characteristic of “vulnerability” which should be extended on buildings and population.

Critics of the Standard Objects of Impact and Response (OBIR) in Use

There was proposed a more accurate unification and standardization of OBIR, which are traditionally the basic elements of the scale. First of all, it is related to the objects of the built environment for which the classification of vulnerability being used in EMS-98 is formally accepted in a whole but must be filled with special regional content that can be done owing to the catalogues of vulnerability. It is obvious that for keeping the uniqueness and continuity of the scale the circle of standard OBIR must be conservative and carefully increased with accumulation of sufficient experience of consequences of the earthquakes. Thus, the standard OBIR of the building environment are to be not only mass as for their construction type but to have an indisputable assessment of the class of their vulnerability basing on the experience of damaging and destructive earthquakes they have passed through before. Basing upon the said above the suggestions on including tall buildings, artificial slopes of railways and highways, pipelines, etc. into the standard OBIR require the special analysis, discussion and, in any case, should be included in the scale after a long preliminary approbation.

The author considers that the history of the earthquake experienced by the particular OBIR as a causal factor of its state and of the expected level of the future seismic impacts is to be regarded and reflected in the estimation of vulnerability of this object.

Considerable disadvantage of standard OBIR is insufficient accuracy of their quantitative gradation in structural vulnerability explained by a little number of different OBIR, which have passed the recent earthquake. Before and until now the built environment was subdivided into three groups of buildings by the MSK scale or into six groups by the MMSK scale coalescing one or another group by the similarity of the construction type. It caused a lot of mistakes because not always the technical damageability and the damage of a traditional masonry house was higher than of the modern RC frame one. Nowadays it is suggested to graduate the construction vulnerability of OBIR for the IMSK scale basing on the estimations of their damageability and damage formation not paying any attention to the construction type of OBIR.

Unification of Structural Vulnerability Assessment

After Spitak earthquake, Armenia, 1988, the author offered (Klyatchko,1994a,b) an approved classification of structural damages and 10 levels of the structural vulnerability consisting of 5 main levels (underlined) and 5 intermediate ones. They are arranged in order of increasing of vulnerability which is estimated by the size of the expected structural damage (in percentage of the value of the OBIR being considered) and include:
z - zero, **n** - negligible, **s** - slight, **l** - light, **lm, m** - moderate, **mh, h** - high, **vh, f** - full.
Later, the same conclusion on the use of “vulnerability” as of the reconciling expert characteristic in the analysis of the damage formation was made by the authors of the European macroseismic scale, where 6 classes of the structural vulnerability were offered. For all these offers to be linked, the author made up the harmonizing conformity in 1996 (Table 1).

Table 1 shows the correlation which was taken by the author to assign the level (class) of structural vulnerability of mass buildings by introducing two boundary classes in addition to 6 classes of vulnerability developed in the EMS-92: O (outstanding, that is worse than A) and G → H (that are better than F). The consequences of the earthquake in Bam (Iran, 2003) demonstrated the expediency and even necessity of introducing the special O class for very weak buildings the collapse of which is fatal for the dwellers, the number of such buildings being large in the developing countries. As for the G class, such gradation which extends the classification of the structural vulnerability is necessary for the buildings of highly required reliability (life facilities, critical objects and objects for emergency management). Such extended classification of the structural vulnerability of the built environment is offered for the IMSK scale.

The list of well-known standard OBIR for assigning the intensity is advised to be created on the basis of buildings damaged by the earthquakes with its extension by modern analytic estimations of their structural vulnerability and damageability.

Table 1. Dependence between the structural vulnerability, the degree of the building's damage (d) and the economic loss (D).

Construction damage (%)	Levels of vulnerability								
	n	sl, ll	L	lm	m	mh	H	vh	f
Range of values	< 0.1	0.1-1	1-3	3-10	10-35	35-60	60-80	80-100	100 %
Mean value	0	0.05	1.5	5	20	50	75	100	100 %
Degree of damage-d MSK/EMS	0		1	2-3		3-4	4-5		5
Class of vulnerability by the EMS-98 scale									
	(H)	(G)	F	E	D	C	B	A	(O)

In doing so, to retain the heredity of the previous earthquake disaster experience and the continuity of the scales the levels (classes) of vulnerability are assigned, at first, to the well-known buildings which have already experienced the earthquakes (which intensity values are indisputable) and, then, to the former basic OBIR when assigning the intensity of the earthquake. In other words, the level (class) of vulnerability of these buildings is to be in exact correspondence with the intensity, which was assigned for it before. Hence, instead of very rough and outdated subdivision of the built environment into not clear defined (from the position of the up-to-date building) the constructive types, the vulnerability of which is fluctuating in a very broad and overlapping range, the direct assessment-assigning of the structural vulnerability class which is correlated with the intensity scale, is introduced (see table 2).

Then, it will be justified and legal if the vulnerability of a frame house is soundly assessed much more higher than of a stone one. Of course, both the highest knowledge and experience of the experts and the methods of processing the information received, e.g. using of method of logistic estimations and system analysis – MELESA, (Klyachko, 1987, 1995) are of the most importance. Therefore, for some time, the classification of vulnerability of buildings should be accompanied by the previous rough classification of the building's types accepted in the MSK and the MM scales. From this point of view, the Encyclopedia of the Housing vulnerability, which was created by the initiative of the EERI with participation of a large number of specialists from different countries of the world, has the highest value.

About Human Vulnerability

A lot of the said above is related to the OBIR, which are the representatives of the animate nature, i.e. to the people of different seismic experience, culture, education, religion and psychophysical state who react to the earthquake differently. There is no differentiation between the people in assessment of their sensations and responses to the earthquakes. An attempt to classify the people by their degree of psychic balance and seismic vulnerability is considered by the author to be possible and useful. Particularly, such works are carried out by Ye. Fridman (CENDR). For last 10 years new questionnaires for the people who experienced the earthquake were developed and approved; the problem of human seismophobia (drastic growth of groundless traumatism, exacerbation of chronic ailments, miscarriages, etc.) after noticeable earthquakes was set and investigated; the panic of the residents being evacuated from the multi-storied buildings and fatal cases in different buildings at moderate (non-damaging) earthquakes, etc. were also investigated. These various features of human respond and behavior during earthquakes were taken into account when drawing up the improved instructions for the population.

Table 2. Relation of damage grades to intensity degree for buildings of different vulnerability class VULC/expert level of earthquake resistance (EXLER).

Intensity	VULC	EXLER	Grade of damage (d) 1	2	3	4	5
VI	A		many	few	very few		
	B		many	few			
	C	~7	few	very few			
	D	~8	few				
	E	~9	few				
	F		very few				
	G						
VII	A			many	very few		
	B			many			
	C	~7	many	few			
	D	~8	many	very few			
	E	~9	few	very few			
	F		few				
	G		very few				
VIII	A				many	very few	
	B			many	few	very few	
	C	~7	few	many	few		
	D	~8	many	many	very few		
	E	~9	many	few			
	F		many	very few			
	G		few	very few			
IX	A					many	few
	B					many	very few
	C	~7				few	
	D	~8		many	many	very few	
	E	~9		many	few		
	F			many	very few		
	G			few			
X	A/B						many
	C					many	few
	D			many	many	many	very few
	E				many	few	
	F				many	very few	
	G			few	few		

many - many (≤60%) few - few (<20%) very few - very few (≤7%)

But the effect of impact of the earthquake on people should be not the main but the secondary factor when assigning the intensity because evaluating the health, receptivity and vulnerability of the people is not less difficult than the vulnerability of building constructions. Moreover, the vulnerability of people is of the 2^{nd} type, i.e. it depends significantly on the seismic behavior of the building in which the people are located.

It is certainly necessary to study this important problem but inclusion of population into the scale as a component of OBIR seems to be untimely. This factor of risk is recommended to relate to that group into which the soil conditions, density of population and others are included. It will allow to study the influence of this factor of risk on the consequences of the earthquake better.

One should strive to assign the intensity which is not valid for one event (for single shock) only, that is by total macroseismic effect of a large number of shocks (for example – "swam" of earthquakes) but also to assign it corpuscularly for the fractional events. Thereby the basics of the IMSK scale and seismic building code are harmonized. That's why the engineering investigation of the consequences of the earthquake is to begin immediately after the first seismic event and include the description and behavior of OBIR in action (accumulation and development of damages, etc.) in correlation with the seismic impact.
There are certainly a lot of other aspects of the macroseismic scale, which are to and can be improved. All of them are given in detail in the framework of Federal Russian Programs "SeismoProtection", "Seismic safety of the Buryat Republic" and "Seismic safety jf Russia" (Aptikaev, 2000,2006; Klyachko, 2000a, 2003).

Application of the IMSK Scale for Designing New Structures and for Earthquake-Resistance Assessment of Existing Ones

Is it correctly to apply the earthquake intensity for estimating structural damage or not, i.e. is inverse task solution permissible?

The application of the intensity for assignment of the design seismic loading on the structures and the further assessment of probable earthquake damage is not correct in principle because the intensity of the earthquake is assigned by definition after the engineering investigation of past earthquakes according to observed damageability of buildings of different well known construction types (OBIR) i.e. buildings of different vulnerability classes. Hence, the opposite application of the initial definition results in the previously known identity. Inverse use of this definition is permissible only in the case of comprehension of the essence of this definition to avoid mistakes. For example we should never forget that when intensity is assigning, the soil conditions (i.e., soil-structure interaction) are not taken into consideration. Thus such approach is admissible in those countries where the seismic intensity maps are used for the design seismic loading and/or where the long-term strong motion observation is not developed enough and the records are absent.
In doing so, we must remember about obligatory correspondence of earthquake resistance level (7, 8 or 9) to serviceability limit state, which is described and given in advance. Special scale of various (desirable, acceptable and permissible) serviceability limit state of buildings is developed by the author and demonstrated in table 3.

Usually, when special load combination (seismic combination) is under consideration, chosen serviceability limit state must not be worse than № 3 (yellow tag). If a very rare emergence load takes place, serviceability limit state № 4 may be permissible. Here we have to take a note that damage grades 3a and 3b are different correspondently by impossibility and low probability of fatalities (due to damage of non-structural elements). In most of cases for earthquake-resistance calculation and for detailed risk analysis it would better to use the structural response on the seismic impacts assigned by the earthquake records (PGA, displacements or energy characteristics).

Generalization

Thus the IMSK intensity scale, in the author's opinion, is to have a more progressive macroseismic part, which should be unified for all countries and regions of the Eurasian economic community. In future the IMSK scale may become unified for all seismo-prone areas worldwide.

Table 3. Scale of structural serviceability limit states - SALS /apply color tag scale - ACTS

Category of SALS	SALS description	Color of tag	Damage grade, d	Notes
1.	Full suitability (normal serviceability, no limitation)	Green	0 -1	Current maintenance
2.	Suitability (full service with limitations)	Green / Yellow	2	Special maintenance
3.	Limited suitability	Yellow	3 a	Service suspension; short time staying people; structural restoration
4.	Not fit for guaranty human safety provision	Yellow / Red	3 б	Emergency evacuation is necessary; strengthening is possible
5.	Absolutely not fit for human safety and structural integrity provision (high collapsibility) Partial (elementary) structural failure	Red	4	Emergence management incl. guarding or demolition of structure
6.	Full structural failure	Black	5	Emergence management incl. rescue works,_disaster medicine etc.

Thereby, the complex approach can be realized but, at the same time, it is clear that no scale of intensity can cover and take into consideration all discrepancies in diagnostics of intensity assessment (national, cultural, etc.).

As for the instrumental part of the scale, this part, in the author's opinion, should not be unified; it should be a regional supplement to the macroseismic scale and reflect the regional peculiarities of the seismic impact. The regional catalogues of vulnerability of the built environment and, perhaps, the generalized characteristics of seismic vulnerability of population of the region are to be the supplement. It is desirable to develop the special manual for the scale IMSK on its use linked with the manual of post- earthquake investigation. In doing so, of especial importance is the development of the unified rules of the use of the intensity, which is to be assigned beforehand in disaster scenarios (Klyatchko, 2004, 2006) and other sections of the risk analysis with permitted and restricted spheres of application.

The scale is supposed to be accompanied with accepted terms and definitions without which the professional mutual understanding inside the multidiscipline community of people who deal with prevention and mitigation of disasters is impossible.

As a result, the complex project of the improved IMSK scale of intensity of the earthquakes consists of the following parts:
- Standard “Scale of the earthquake intensity” (short version);
- IMSK Macroseismic scale, including The Commentary and Rules on using (detailed version);
- Regional instrumental scales for earthquakes of different intensity;
- Regional Catalogues of seismic vulnerability of OBIR;
- Recommendations on assigning the seismic intensity by the results of post- earthquake investigation.

Conclusions

Summing up the above-stated, the authors note the necessity of a working discussion on the current proposal on IMSK for harmonizing and unification of the up-to-date view on the scale of earthquake intensity with regard to other suggestions and opinions.

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