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URBAN SEISMIC RISK REDUCTION IN SLOVENIA, YUGOSLAVIA - AN INTEGRATED APPROACH

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SUMMARY

Thirty-one percent of the republic of Slovenia,northwest Yugoslavia, including the capital city of Ljubljana, lies in seismic zones of degree 8.0 and 9.0 on the MCS scale. These areas are inhabited by 44% of Slovenia's population, about half of whom live in "older buildings", i.e. those built before the first federal seismic code was introduced in 1964. The behaviour of these buildings in past earthquakes, together with extensive experimental investigations, have formed the basis for recent vulnerability studies. Present efforts to implement urban seismic risk reduction programmes, aimed primarily at the evaluation of the most endangered buildings, are described.

INTRODUCTION

Like most of Yugoslavia, the republic of Slovenia, located in the northwest part of the country, is a seismically active region. The strongest recorded earthquakes, with epicentres in Slovenia, took place in 1511 (the Idrija Earthquake : macroseismic magnitude: 6.0 - 7.0, epicentral intensity: 9.0 - 10.0 MSK-64) and in 1895 (the Ljubljana Earthquake: macroseismic magnitude: 6.0 - 6.1, epicentral intensity: 8.0 - 9.0 MSK-64). According to the most recent historically-based map of regional seismicity, adopted in 1982, the republic is divided up into 15 zones where earthquakes with maximum expected intensities ranging from 6.0 to 9.0 on the MCS scale can be expected. A map of these zones is given in Fig.1, and some interesting characteristics (Ref.1 & 2) of the individual zones and their population density, taken from the 1981 census, are shown in Table 1.

From Table 1 it can be seen that the density of population in the zones of higher seismicity (8.0 and 9.0 MCS) is, in general, greater than that in the remaining zones of lower seismicity. In particular, the density of population is far above average in the Ljubljana zone "9c", which includes the southern part of the capital city itself. As much as 44% of Slovenia's total population lives in seismic zones of degree 8.0 and 9.0 MCS.

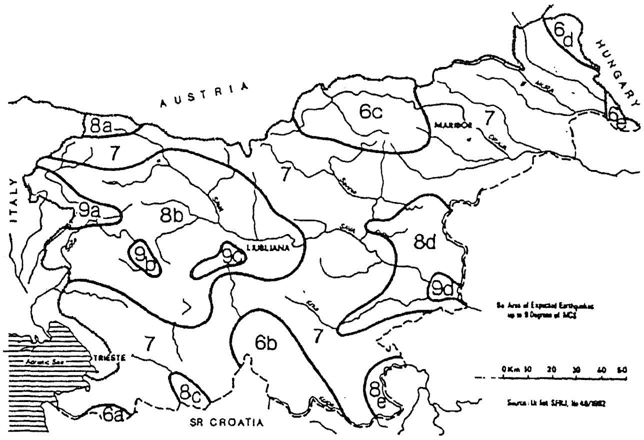

Fig.1 : Seismic zones of Slovenia

Table 1: Distribution of population in the seismic zones of Slovenia

Seismic zone, MCS	Area in km2	Proportion of total area	Population, 1981 census	Proportion of population	Population density per km2
9a Tolmin	398	1.96%	15240	0.81%	38
9b Idrija	111	0.55%	10569	0.56%	95
9c Ljubljana	233	1.15%	99563	5.27%	427
9d Brežice	121	0.60%	17539	0.93%	145
9 Total	863	4.26%	142911	7.57%	166
8a Kranjska gora	131	0.65%	5068	0.27%	39
8b Western alpine	3979	19.64%	546708	28.97%	137
8c Ilirska bistrica	133	0.65%	10771	0.57%	81
8d Posavje-Kozjansko	1029	5.08%	105441	5.59%	102
8e Bela krajina	198	0.98%	16785	0.89%	85
8 Total	5470	27.00%	684773	36.29%	125
7 Total	11457	56.55%	920160	48.77%	80
6 Total	2469	12.19%	139068	7.37%	56
All zones	20259	100%	1886912	100%	93

The most recent data about the distribution of residential buildings in Slovenia according to seismic zone and year of construction (Ref. 3) are given in Table 2, in terms of total usable floor space in m2.

Table 2 : Distribution of residential buildings in Slovenia, according to year of construction and seismic zone (in thousands of sq.m. of usable floor space)

Seismic zone, MCS	Year of construction				
	Up to 1900	1901-1965	Up to 1965	1966-1980	Up to 1980
9	483	1337	1820 (4.9%)	1304 (3.5%)	3124 (8.4%)
8	1881	5208	7089 (18.9%)	7440 (19.9%)	14259 (38.8%)
6+7	2883	7983	10866 (29.0%)	8925 (23.8%)	19791 (52.8%)
All	5247	14258	19775 (52.8%)	17669 (47.3%)	37444 (100%)

Note: The figures for 1965 are the nearest available to those for 1964, when the first federal seismic code was adopted.

It can be seen from Table 2 that by the end of 1980 about half of all residential buildings still pre-dated the coming into force of the first federal seismic code in 1964. About 160 thousand such "older buildings", with a usable floor area of almost 9 million square metres, are located in the zones of higher seismicity, 8.0 and 9.0 MCS. From the various data available concerning the distribution of non-residential buildings, e.g. those of industry and commerce, it follows that about half of all Slovene industry, too, is located in these zones. A considerable proportion of these buildings, too, were built before 1964. The question which now arises is how the seismic vulnerability of all these older buildings can be reduced most effectively.

THE SEISMIC VULNERABILITY OF OLDER BUILDINGS IN SLOVENIA

Up until about the end of the nineteenth century, most buildings in Slovenia were built of stone-masonry, brick-masonry or mixed stone-and-brick masonry, using lime-sand mortar. Floor structures were supported by wooden beams resting at either end in cavities of the load-bearing walls. In urban centres, these buildings reached a height of 4 or even 5 storeys, whereas rural buildings usually had 1, 2 or, more rarely, 3 storeys.

In the Ljubljana Earthquake of 1895 many buildings in the city and its environs were badly damaged, and some were later demolished. As it was observed that previously existing steel tie-bars had in many cases prevented serious damage, a law was passed in 1896 requiring that all new buildings in the province should have such tie-bars incorporated into their load-bearing walls at each inter-storey level. From 1920 onwards,in urban areas there was greater use of reinforced-concrete floor slabs instead of wooden floor structures. During the period between 1945 and 1964 there was no federal seismic code, although Yugoslav technical regulations for loads on buildings required that horizontal loads of 1.0 - 3.0% of a building's weight be taken into account in design calculations.

One month before the Skopje Earthquake of 1963, a Slovene seismic code was adopted, which in many ways paved the way for the first federal seismic code of 1964. This code required that new masonry buildings be constructed with stiff and well-anchored floor structures, and that they be reinforced with horizontal and vertical reinforced-concrete tie-beams. Regular layouts of walls, and maximum permitted distances between transverse stiffening walls were specified,as well as the use of cement-lime-mortar for all buildings in regions of high seismicity. It was during the Skopje earthquake that numerous multi-storey brick-masonry buildings not satisfying these requirements were badly damaged or collapsed, which initiated, at Ljubljana, an extensive programme of experimental investigations into the seismic resistance of brick-masonry buildings .

The Kozjansko Earthquake of 1974, in mid-eastern Slovenia, (macroseismic magnitude: 5.0, epicentral intensity :7.0 - 8.0 MSK-64) caused a lot of damage to the seismically-weak one and two storey stone-masonry buildings in a less developed rural area, again stimulating a programme of experimental research (Ref. 4). Only 2 years later many stone-masonry buildings in the Soča Valley region, in western Slovenia,were heavily damaged or collapsed as a consequence of the Friuli earthquakes of 1976. Much data on the extent and nature of damage to buildings of this type was assembled by researchers , and methods of repair and strengthening were developed and implemented on a large scale (Ref.5). Some interdisciplinary investigations into the effects of post-earthquake renewal on socio-economic processes, and into the economic effects of strengthening, were also carried out (Ref.6). Even more data on the seismic performance of different types of buildings were obtained after the disastrous Montenegrin Earthquake of 1979. On the basis of damage caused to 40000 buildings in 300 different settlements, many of them being older masonry buildings, empirical vulnerability functions have been derived (Ref. 7).

Soon after the Friuli earthquakes, in 1978, a special law was passed in Slovenia, requiring the upgrading of seismically hazardous buildings of greater importance to the community. In the law of 1978 these buildings were only defined in general terms, but in 1986 a full list of types of buildings of greater importance was added, including hospitals, schools, important monuments and administrative buildings,etc. This law requires that all such buildings be surveyed and their seismic resistance assessed,and that urgently needed strengthening works should be carried out as soon as possible. However, for the time being difficult economic conditions have prevented the realization of this work. A considerable number of individual buildings have been strengthened, but from a structural point of view not always satisfactorily, since the degree of necessary strengthening is insufficiently defined by the technical regulations. Certain recommendations concerning minimum strengthening levels in the case of urban renewal of older buildings were issued in Slovenia in 1985, and in 1988 a definition was provided, in the federal code, of cases when older buildings must be strengthened to comply fully with the present seismic code.

RECENT PROGRESS IN URBAN SEISMIC RISK REDUCTION STUDIES

In urban areas, seismic vulnerability studies have progressed the furthest in the capital city of Ljubljana, where many historic buildings with central functions are located. In other towns,apart from simple civil defence preparations such work has been limited to that concerned with the renewal of individual buildings or complexes of buildings within old town centres.

The city of Ljubljana is located on alluvial soil. Its southern part (9.0 MCS) lies in the vicinity of the Karst, on relatively recent lake deposits (sands, marls), whereas the northern part (8.0 MCS) lies on better ground consisting of river gravel deposits and conglomerate. One sixth of Slovenia's total population lives in the city, and a large proportion of its buildings were built before 1964 and the first federal seismic code. The seismic threat to Ljubljana may therefore be considered the most serious in Slovenia. In the early 1970's,to meet future planning needs seismic microzoning of the city was carried out, according to which Ljubljana has been divided up into zones with six different seismic coefficients, ranging from Ks = 0.04 (8.0 MCS, good soil conditions) to Ks = 0.12 (9.0 MCS, poor soil conditions).

Work so far carried out in determining the seismic vulnerability of Ljubljana's older buildings, and possibilities for urban seismic risk reduction, includes the following: (1) urban renewal studies, defining possibilities for increased building exploitation through aseismic repair and strengthening (2) compiling of a list of more important older buildings, with an assessment of their seismic vulnerability, (3) vulnerability studies of special categories of buildings, e.g. school buildings (Ref.8) and unreinforced-masonry tower-blocks (Ref.9), (4) parametric studies of the vulnerability and seismic risk to older residential and mixed-purpose buildings in individual planning zones, taking into account population density (Ref.10). This work has been backed up by extensive experimental studies of the structural properties of older masonry buildings, including laboratory and in-situ tests of original and strengthened wall elements (using reinforced plaster layers and cement-grouting), model shaking-table tests, and forced-vibration and ambient-vibration tests of buildings to determine their dynamic characteristics.

In recent years it has been possible,to a certain extent, to include the findings of such studies in general urban planning documents, one of whose aims is to achieve a long-term improvement in the seismic safety of the city's inhabitants. Such inclusion has undoubtedly enriched these documents.

CONCLUSIONS

With respect to the relatively large number of seismically inadequate "older buildings" (mostly unreinforced masonry) in Slovenia's areas of high seismicity (8.0 and 9.0 MCS), including the capital city of Ljubljana, much work needs to be carried out on the systematic determination of their vulnerability and the preparation of proposals for reducing urban seismic risk. The first results of strengthening projects, particularly in urban renewal programmes, are already apparent, but greater efforts are needed to identify accurately the seismically most threatened buildings, both those of greater importance to the community and those where a high density of users coincides with seismically weak structures. Further improvements are also urgently needed in the technical regulations with respect to definitions of the required levels of aseismic strengthening of older buildings. Only if these conditions are met will it be possible to create truly satisfactory planning procedures for medium-term and long-term urban seismic risk reduction in Slovenia.

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