50 YEARS SINCE THE SKOPJE 1963 EARTHQUAKE – IMPLICATIONS FOR AUSTRALIAN BUILDING STANDARDS

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Abstract

The 1963 Skopje earthquake, Mw 6.1, struck Skopje, Macedonia, on July 26, 1963. It killed more than 1,070 people, injured around 4,000 and left more than 200,000 people homeless, destroying about 80 percent of the city itself. Public buildings, schools, hospitals and many historical monuments suffered very heavy damage. In the aftermath of the earthquake, relief in the form of finances, medical, engineering and building supplies was sent from some 80 countries through the United Nations. As part of the UNESCO and State programs, an Institute of Earthquake Engineering and Engineering Seismology (IZIIS) was established in order to assist and supervise the post earthquake reconstruction, and revitalise and develop the City of Skopje.

In the post-earthquake period in the then Yugoslavia, the National Building Codes were revised and a new earthquake standard was recommended. The current development and construction process continues to address earthquake concerns, particularly in its requirement for reviews of building design and planning options.

The lessons learnt from such a strong earthquake are relevant for consideration in Australian urban areas, the magnitude of the Skopje earthquake is a 'design earthquake' for Australian cities yet few buildings have been designed and built to survive such an earthquake here. In particular all schools, hospitals and post-disaster facilities should be inspected to assess their capacity to remain standing after such an earthquake and strengthened if they fail the test. Serious consideration should be given to establishing an Institute of Earthquake Engineering in Australia; to train engineers and building certifiers from Australia and Southwest Pacific countries, and to regularly upgrade and standardize their earthquake codes.

KEYWORDS: Earthquake damage, earthquake engineering, earthquake codes

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INTRODUCTION

The Skopje earthquake of 26 July 1963 was the most destructive event in the history of the Republic of Macedonia and caused losses of about 15% of the gross national product of the Yugoslavian federation for that year. The earthquake was unique among other catastrophic earthquakes in that period in Europe and the Mediterranean region and triggered a huge interest and activity by governments, scientists and engineers throughout the world. The Skopje earthquake raised for the first time at the highest level the need for organised and sustained efforts for the implementation of Building Standards and the development of strategies for disaster management. Earthquake catastrophes were no longer only local problems, they were recognised as complex economic, technological, political and social challenges for the stricken region as well as at national and international levels. In the aftermath of the earthquake, finances, medical, engineering and building supplies were sent from some 80 countries through the United Nations.

In order to assist and supervise the post earthquake reconstruction and development of the City of Skopje, a new Institute of Earthquake Engineering and Engineering Seismology IZIIS, was established at the University "St. Cyril and Methodius" in 1965 based on the recommendation of the International Consultative Board, UNESCO and the Government of Republic of Macedonia and City Authorities. The Institute carries out a large number of applied and development research projects and provides services for the design and analysis of sophisticated civil engineering structures. Besides cooperating directly with universities, institutions and the economic sector of the Republic of Macedonia, IZIIS has organized an intensive international programme addressing building design and planning options including emergency management.

These are lessons we should heed in Australia. Much as there is a need for an equivalent body such as IZIIS in Australia and/or New Zealand to provide scientific and engineering advice both locally and for the SW Pacific and our near north, it is unlikely to happen until a destructive earthquake like that at Skopje strikes Australia. Perhaps New Zealand is adequately served with its Earthquake Commission and Natural Disaster Fund though its focus is narrowly aimed at New Zealand rather than the broader region. There is no doubt that most Australian cities face a threat from a similar sized earthquake and are as ill-prepared as was Skopje, with un-reinforced masonry a dominant building material in Australian cities and few engineers or architects educated in earthquake engineer principles or post-disaster response.

SEISMICITY OF MACEDONIA AND SKOPJE AREA

The territory of Macedonia, situated in the Mediterranean seismic belt, is an intra-plate area of high seismicity. Even from an incomplete documentation it can be seen that Macedonia experienced numerous medium-to-large earthquakes, the largest in the last century occurring on the border with Bulgaria in 1904 with an estimated magnitude of 7.5+/-0.4 (Hadzievski, 1976).

In the central zone named after the biggest river Vardar, there appears a region where earthquakes occur quite frequently with its Skopje part considered to be the most mobile. Before 1900, the written documents of Skopje mention an earthquake catastrophe at Scupi (a Roman name for the city) in 518 A.D. and another in 1555. The old Scupi was situated about 4-5 km NW of the centre of the present Skopje and ground fissures extending over 45 km in length and up to 4 metres in width were reported. The earthquake of 1555 had demolished parts of Skopje too, both earthquakes estimated to be of a maximum intensity of XII on the Mercalli scale.

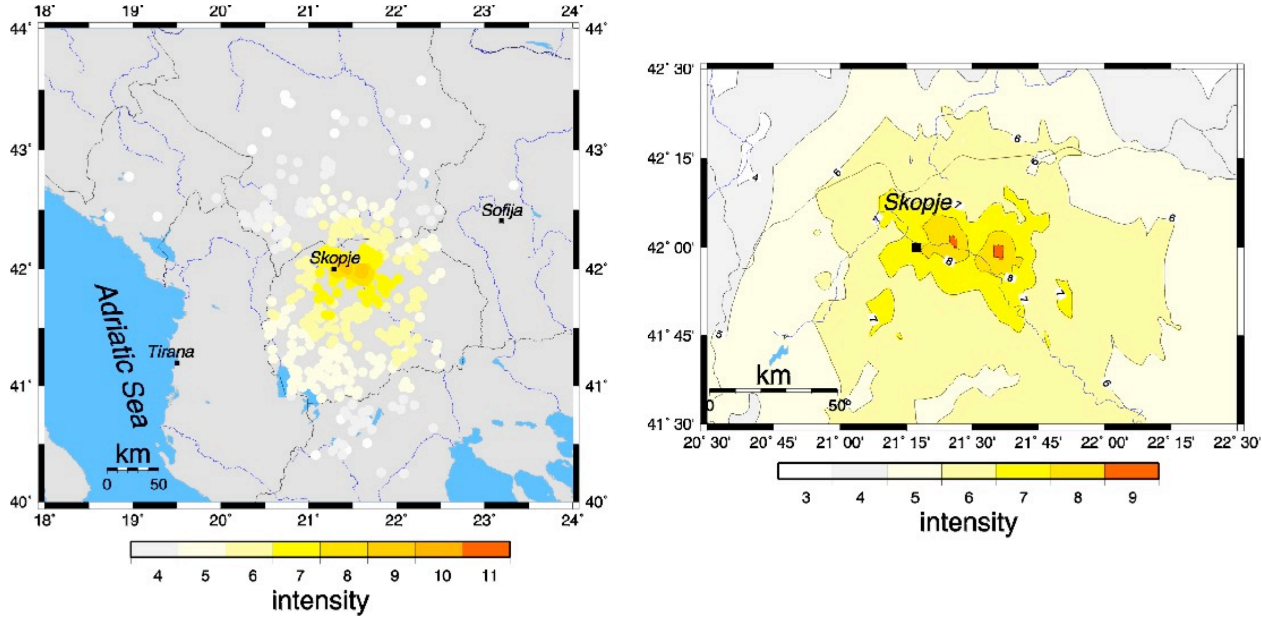
During the past century, the Skopje area was affected by a swarm of damaging earthquakes in 1921, grouped roughly 15km from the present day city with magnitudes of 4.6 to 5.1 and intensities of around VII-VIII on the Mercalli scale. Besides the local earthquakes, Skopje has also suffered several times from regional earthquakes occurring at larger distances of a hundred kilometers. Although there was general information on the seismicity and geological conditions of the Skopje valley prior to the 1963 earthquake, it was not used much for urban planning and construction apart from consideration made for geotechnical conditions for the sites of specific projects, which was required by the Temporary Code for Construction. The first seismological map of Yugoslavia was published in 1950 in Belgrade, zoning was done in terms of the intensities of earthquakes that occurred in the period from 360 A.D. to 1950. The existing Yugoslav building code, although somewhat primitive in its seismic provisions, recognized the seismicity of the country and specified minimum seismic design coefficients. Had this code been followed, taking into account the need for ductility as well as strength in a structure and the influence of nonstructural components upon the behavior of a structure, the 1963 Skopje earthquake might have been much less of a disaster (Berg, 1964).

THE SKOPJE EARTHQUAKE OF 1963

On July 26 1963, at 5:17 a.m., Skopje was hit by a shallow, magnitude M=6.1 (Richter scale) earthquake with an intensity rating of IX (Mercalli scale). The catastrophic event caused heavy losses of life and property, killing more than 1,070 people, injuring around 4,000 and leaving more than 200,000 people homeless. About 80 percent of the city was destroyed and many public buildings, schools, hospitals and historical monuments (Fig. 1) were badly damaged according to various reports (for example UNESCO, 1968). The material losses were estimated at about one billion US dollars.

Most of the territory of the Republic of Macedonia (25,700 km^2) was shaken with intensities varying between V and IX on the Mercalli scale, the lowest MM IV. This intensity was also observed in Sofia (Bulgaria) at a distance of about 173 km, and in Thessaloniki (Greece) at a distance of 195 km from Skopje. The observations from Podgorica (186 km) and Belgrade (323 km) are consistent with local intensities of MM III. The felt area of the July 26, 1963 Skopje earthquake is approximately 200,000 km^2 its focal depth 5 km, and the energy release estimated to be 10^{21} ergs. The map with 668 macroseismic data points of the earthquake and the intensity map of the epicentral area are presented in Fig. 2 (Suhadolc *et al.,* 2004). There were no accelerometer recordings of the 1963 Skopje earthquake and the basic parameters of the focal mechanism of the earthquake deduced from the macroseismic data indicate compression stresses with a trend of ENE-WNW and dilatation stresses along the NNW-SSE line.

Figure 1: Images of damaged buildings from the 1963 Skopje earthquake



(a) (b)

Figure 2: Macroseismic data of the July 26, 1963 earthquake (a) and detailed contour map of the epicentral area (b)

POST-EARTHQUAKE RECOVERY AND RECONSTRUCTION

The analysis of damaged and destroyed buildings made after the earthquake revealed both design and construction defects. The distribution of damage is shown on Fig. 3 (Petrovski, 2003). Private houses with a ground floor and one story failed or were badly damaged in high numbers since no horizontal seismic forces had been taken into consideration in their engineering design. The buildings mainly had massive load-carrying walls constructed of masonry or solid bricks laid using lime and cement mortar, but without reinforced concrete columns and beams, which would provide a strengthened integral structural system. In the pre-earthquake period 1950-1962, many housing blocks were constructed with a ground floor plus four stories in the classical structural system, with two facades and one set of middle load-carrying walls made of solid bricks. The failure of this type of buildings as a result of the earthquake resulted in the heaviest loss of life. The main reason for their collapse was that there were no structural elements to withstand the horizontal forces, particularly in the transverse direction of the structure. Housing blocks and buildings or towers higher than 10 stories were not seriously damaged. That can be explained by the fact that the earthquake was local, the predominant frequencies were far from the fundamental frequencies of the buildings and therefore resonant conditions were avoided. The other factor was the consideration of horizontal wind forces in the design of these buildings, the resistance proved sufficient against horizontal earthquake forces.

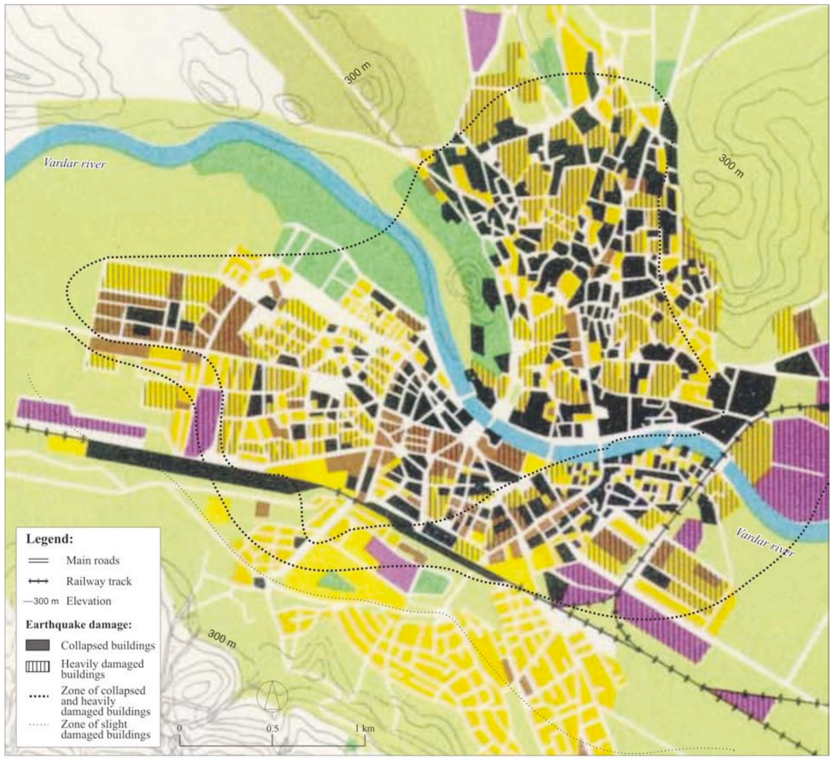


Figure 3: Damage distribution of buildings due to July 26, 1963 Skopje earthquake

Generally speaking, buildings with brick masonry wall suffered more than any other type and accounted for the highest number of deaths. Mixed construction also suffered considerably. Although many of those buildings did not collapse they were left completely shattered, beyond repair. Old adobe structures, particularly those with timber bracing, resisted the shock with some damage but behaved far better than the brick masonry or the mixed structures. Reinforced concrete skeleton structures suffered comparatively little damage and only two small structures of that type collapsed. As mentioned above tall structures up to 15-storeys high, performed far better due to the frequency content of the earthquake. They were constructed with more care and, in some cases, wind forces were considered in the design. Finally, pre-stressed structures were totally destroyed after the collapse of their supporting columns.

The local site-soil conditions of Skopje comprising alluvial sediments cannot be fully responsible for the damage that the city suffered. The design of modern structures, with the exception of the brick masonry wall bearing buildings, was in general adequate, although in some cases a little under-designed and with considerable improper detailing. It is recognized that those modern methods of design were not followed up by equally advanced methods of construction and quality of materials which was found to be of a foremost importance.

The reconstruction of Skopje was carried out over a period of more than 10 years after the earthquake. Some 18 settlements were constructed in the city and suburbs as residential areas with prefabricated houses constructed of light timber elements. The highly damaged flats were replaced with newly constructed or repaired units. The reconstruction was done on two levels. The immediate one involved repair of those buildings that were not heavily damaged, and calculations proved that their demolition was not economically justified. The repair was mainly performed at the ground floor level of the buildings where most of the damage was concentrated in the structural elements such as reinforced concrete columns, beams and massive load-carrying walls.

The second direction of reconstruction was intensive construction of new buildings. After the earthquake, an international architectural-urban competition was opened for reconstruction of the city centre of Skopje. The first prize was awarded to the Japanese architect, Kenzo Tange. Although the original idea of that work was not fully implemented its basic concepts were preserved and incorporated in the Master Plan of the City of Skopje that followed. According to the Master Plan, the construction of the "City Wall" started in the very centre of the city in 1969, consisting of multi-story residential buildings of two types: residential blocks up to 6-storeys in height and residential towers of ground plus l2 floors. Another construction of a large building complex east of the city centre for accommodation of 80,000 inhabitants started in 1975. In each of the new settlements, there were other types of structures, many of them with reinforced concrete walls and other types representing a combination of reinforced concrete walls and reinforced concrete frames for high-rise commercial and business buildings (Fig. 4).

Figure 4: Examples of structures built within the reconstruction period

Besides the restoration of damaged buildings, Skopje reconstruction also applied new elements of development and modernization. This refers to all vital activities in economy (industry, agriculture, traffic, trade, etc.), infrastructure (communication lines, railway network, new airport, post offices, water supply, regulation of the Vardar river course, central heating of Skopje city, electric power supply, etc.) as well as social standard (education, culture and arts, health and social care systems).

PAST AND PRESENT SEISMIC RISK INVESTIGATION

The Skopje earthquake of 26 July 1963 proved once more that ground acceleration during strong earthquakes can be very high. It also demonstrated that the damage caused was not due solely to the peak ground acceleration, but depended on many other parameters such as ground motion duration, frequency content of the ground motion, capacity of structural resistance, geometrical layout of the building, materials used and the quality of construction that all played a considerable role. In other words, damage caused by an earthquake is the result of many interrelated parameters, among which the amplitude of the ground acceleration is just one component.

Since no strong motion accelerographs or any other strong motion instruments had been installed in Skopje at the time of the earthquake of 26 July 1963, all present knowledge of ground motion intensities and estimates of ground movement is based on microseismic observations carried out immediately after the earthquake and special study on sliding and overturning of typical objects in different parts of the city. From those reports, the peak ground acceleration had been estimated to vary in the range between 30% to 42% g.

After the Skopje 1963 earthquake recommendations were made for: elaboration of a seismic microzoning map for Skopje and the seismic zoning map of Yugoslavia, development of a network of seismological stations; the creation of an Institute of Seismology, Earthquake Engineering and urban planning; the drafting of a code for seismic design; the standardization of construction materials and improvement in the quality of construction. The implementation of the Master plan was organized by UNDP and the Yugoslav government and was under the supervision of commissions of national and international experts. Major components of the Master plan for reconstruction of the city of Skopje included: regulations for a seismic microzoning map of the wider urban area, compulsory implementation of the Temporary Code for seismic design, requirements for detailed investigations of the construction sites and studies to determine the effects due to seismic hazard.

Seismic risk reduction is part of the activities in IZIIS. It starts with determination of the seismic exposure of a region or locality of interest. The initial phase involves specific research into the seismic history of the region, study of the geological conditions with emphasis on seismotectonics, seismic hazard analysis, seismic zoning, definition of seismic design parameters, seismological monitoring and related aspects. Seismic safety of buildings and engineering systems is the next fundamental segment performed through the Aseismic Construction of Buildings assuming the structural safety and vulnerability of buildings, building materials, new technologies in building engineering, rehabilitation of buildings, etc. Experimental verification of theory is tested on models in the Dynamic Testing Laboratory equipped with a 3-D shaking table. Determination of the attenuation relationships and the characteristic site response spectra is of particular importance for the seismic hazard analyses.

Due to the large number of accelerograms (more than 500) collected post-Skopje earthquake from the strong motion instrument network in the former Yugoslavia and Macedonia, it was possible to estimate the characteristic attenuation relationships and response spectra (Fig. 5) for the region (Talaganov and Schmid, 2002).

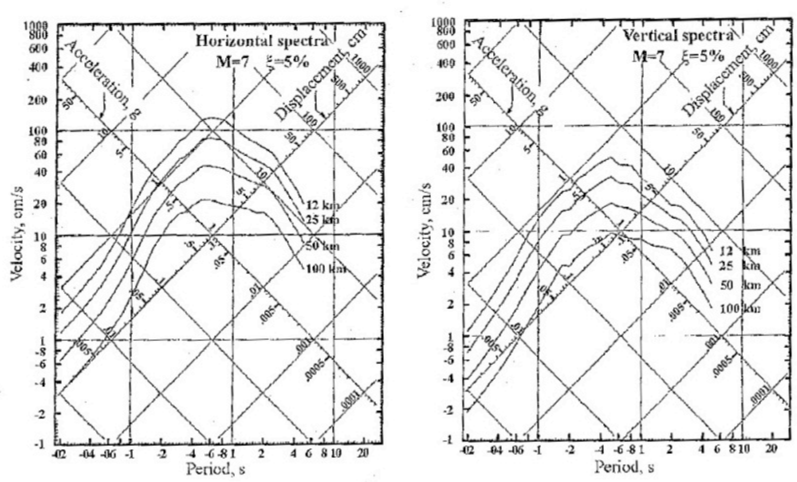


Figure 5: Response Spectra for magnitude 7 earthquake at distances of 12, 25, 50 and 100 km

A large amount of work was devoted in Macedonia on methods of earthquake risk assessment, and establishing scientific criteria for the stability of civil engineering structures under various dynamic conditions. The current development and construction process continues to address earthquake concerns, particularly in its requirement for reviews of buildings design and planning options. The lessons from the Skopje 1963 earthquake and the consequent studies give the possibility of using and incorporating this experience in the seismic risk reduction process in other areas of the world. Then, the development of an appropriate action plan for the local condition would significantly reduce the effects of the scenario earthquake on the urban environment such as the city of Skopje.

EARTHQUAKE IMPLICATIONS FOR AUSTRALIA

Cities in Australia are, like Skopje, in an intra-plate region where strong earthquakes occur infrequently, yet would cause substantial damage and loss if they happen close to populated areas. The largest onshore earthquake recorded in Australia was at Meeberrie Homestead WA, in 1941, where a magnitude Ms 6.9 earthquake severely shook the homestead and burst water tanks and cracked the ground with minor damage reported in Perth 500 km away. The city of Adelaide, SA, experienced a magnitude 6 earthquake in 1902 at less than 100km distance and a magnitude 5.6 earthquake in the outer southern suburbs in 1954 with intensity VIII. There was widespread minor damage many buildings causing losses well in excess of $100 million at today's dollar value. In 1979 the small wheatbelt town of Cadoux WA, was shaken by a magnitude 6.2 earthquake similar in size to the Skopje 1963 earthquake (Sinadinovski and McCue, 2003). There were no injuries, but 25 buildings in Cadoux were extensively damaged (Fig. 6). The damage cost was $3.8 million. Tall buildings in Perth at a distance of 180 km swayed during the earthquake, but suffered no damage.

Figure 6: Damage in Cadoux Western Australia due to the M6.2 June 2, 1979 earthquake

In January 1988 a series of earthquakes with magnitudes 6.3 to 6.7 hit near the Tennant Creek township in the Northern Territory. Two buildings including the hospital and 3 other structures were damaged, and the natural gas pipeline supplying Darwin was crimped and concertinaed requiring repair. The larger earthquakes were felt in Darwin. The total damage was estimated at $2.5 million. To date the most destructive earthquake recorded in Australia happened near Newcastle, NSW in December 1989 with a magnitude of 5.6. It damaged over 50,000 buildings and shut down the Newcastle CBD for two weeks. Effects of the earthquake were felt over 200,000 square kilometres. It caused 13 fatalities, 160 people were hospitalised, and 300,000 people were affected. Some 300 buildings were demolished and the damage cost was about $4 billion.

The Australian Building Code must be re-evaluated to consider the impact of intra-plate earthquakes such as the Skopje 1963 earthquake, especially in the wake of the 2010/2011 disasters at Christchurch New Zealand and focusing on the building stock of old unreinforced masonry structures that are most at risk. Large dams should be subject to a modern dynamic analysis using a close large seismic events such as Cadoux 1979.

CONCLUSIONS AND DISCUSSION

During the last five decades, the development of Skopje has provided a valuable experience in repair, reconstruction and city development following the catastrophic 1963 earthquake. Incorporating modern methods such an event can provide a key for testing and solving problems in the field of urbanization, architecture and civil protection. The main objectives of the newest Master Plan of Skopje are: a review of the latest seismicity of Macedonia, incorporation of the relevant data regarding lifelines and utility systems and development of damage scenarios for the design and maximum earthquakes for emergency management.

Today, Skopje is a modern, highly developed, industrial, socio-economic and cultural urban centre of Macedonia that stretches about 30 km in length and is home to more than 650,000 citizens. The current development and construction process continues to address earthquake concerns, particularly in its requirement for reviews of buildings design and planning options. The lessons for such a strong earthquake as Skopje 1963 in an Australia urban area are many.

Why wait until after a destructive earthquake hits an Australian city to make our cities more resilient, the warnings are obvious with Adelaide suffering damage but no fatalities by good luck in 1902 and again in 1954. Newcastle was not so lucky in 1989 but the death toll could have been much worse. Sydney has been shaken by three earthquakes of magnitude 5.5 within about 100 km since 1960 and most other Australian cities have experienced uncomfortable seismic shaking in their short lifetimes.

The first objective should be to ensure our school children are safe at school, our patients safe in hospital and post-disaster buildings survive and are functional after an earthquake. There are too few trained professionals in Australia, earthquake engineers and architects, who understand the requirements for building resilient structures and thought should be given, learning from Skopje, to establishing an institute of earthquake engineering here teaching down to undergraduate level, to service, not just Australia but the Southwest Pacific where we have a responsibility to provide guidance and support.

Another function of such an institute, learning from Skopje, would be the preparation and regular upgrade of earthquake hazard maps and earthquake codes, for Australia and for neighbouring countries with strong partnerships with professionals from those countries. There is no formal process in place in Australia let alone the southwest Pacific to do this anymore now that Standards Australia has been privatised. The upgrade of the 1979 Australian Standard AS1170.4 was fast-tracked after the 1989 Newcastle earthquake and was finally published in 1993 but another 14 years passed before the next upgrade and then the Australian Earthquake Engineering Society with a volunteer workforce published the commentary, not Australian Standards. We must do better and Skopje shows the way.

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