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METHODOLOGY FOR DRR CITY PLANNING BASED ON SEISMIC HAZARD ASSESSMENT AND MONITORING SYSTEM IN ASHGABAT

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Abstract

This paper presents the methodology to mitigate earthquake disaster using city planning method based on hazard assessment and real-time seismic information system, which is studied in the project "Improvement of the Earthquake Monitoring System in and around The Ashgabat City in Turkmenistan" funded by Japan International Cooperation Agency (JICA) since 2017 July. Technology Transfer Projects donated by JICA has accelerated creation of seismic hazard maps and risk assessments in many countries.

A real-time earthquake monitoring system, including seismographs donated by JICA, in the project will instantly disseminate seismic intensities in Ashgabat City and its vicinity. The main aim of the real-time seismic intensity information system is to rescue people from damaged areas. However, such system may be useless in case of gigantic direct-hit earthquake because many people may die instantly due to pancake crush of buildings in the MSK-64 intensity 10 – 12 areas. In order to avoid such an overwhelming catastrophe, it seems worthwhile to control land use and construction of buildings in the most hazardous areas. A detailed scenario-based seismic hazard assessment will be necessary for a better DRR land use planning.

With enhancement of DRR planning efficiency by additionally controlling land use & building construction in the most hazardous areas, rescue activities will be conducted even more effectively, utilizing the real-time seismic intensity information system in less damaged areas where seismic intensity is 6 or less. In addition to a real-time system, various pre-planned measures such as evacuation plans & drills, enforcement of building safety inspection and indoor safety campaigns at community level are going to be effective as well. Business Continuity Plan (BCP) for private enterprises or central ministries will also be encouraged for a better disaster preparedness.

In the seismic structural design of high-rise buildings and seismic base-isolation buildings in Japan, the predominant periods of the design input ground motions are implicitly taken into account. According to Eto et al. (2002) [1], in the structural calculation (dynamic analysis) of high-rise buildings & base-isolated structures, it is pointed out that the design fundamental natural period has been set to avoid predominant period of input ground motions. This fact shows a certain effect to design buildings by keeping the fundamental natural period far from those of ground motions.

In this paper, a ground classification is proposed by a combination of the average S wave velocity of the ground related to the amplification and the predominant period estimated from microtremors etc.

In this project, in addition to improvement of the observation system by installation of seismometers, several technology transfers related to geophysical exploration ground modeling and zoning are in progress. The methodology for earthquake disaster reduction was discussed during the on-site training in Ashgabat in October 2018.

Underground deep soil structures in Ashgabat City and its vicinity resembles those of Kobe City [Notes] *. It is necessary to detect the most hazardous earthquake zones and control construction in Ashgabat. The monitoring together with the rescue & evacuation preparedness and DRR city planning based on seismic hazard assessment will play a role of both wheel of policy to mitigate earthquake disasters.

Keywords: DRR; seismic hazard assessment; city planning; predominant period; microtremors

1. Introduction

Turkmen-Khorasan zone, as a whole, represents one of links of northern branch of Alpine orogenic belt of Eurasia, connecting structures of Small Caucasus and Elbrus from one side, and Gindukush and Pamir from another. The zone is characterized by high intensity of Alpine folding deformation and presence of clearly distinct zones of deep faults.

Another focal zone of high seismicity is Balkhan-Caspian zone of Turkmenistan (Kubadag mountain arrays, Big and Small Balkhan, Pribalkhan fold, Caspian Sea). Kubadag and Big Balkhan, should be referred to Turonian plate, in terms of tectonics. To the south, Southern-Caspian depression is located, which is formed by non-cohesive new sediments, with depth up to 5 km, and belongs to Elbrus zone. One of the distinctions of Balkhan-Caspian region in terms of seismotectonics is depth of earthquake focuses: shallow ones – up to 20 km in Ashgabat region and deeper ones – up to 40-60 km, in Pribalkhan [2].

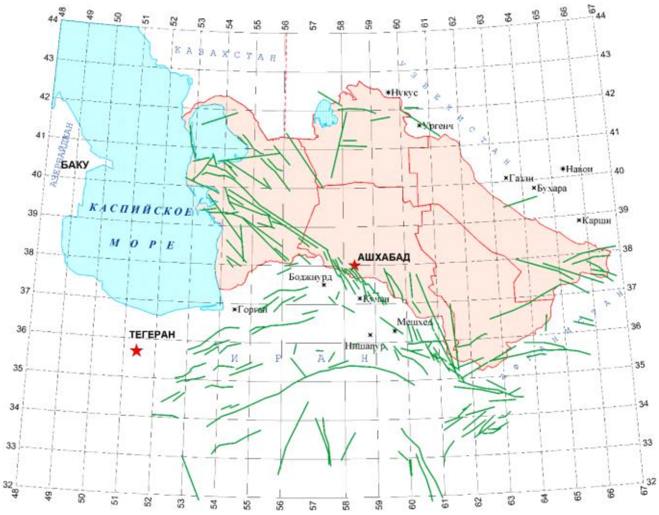


Fig. 1 – Fragment from map of active faults in territory of Turkmenistan and Northern Iran [2]

Ashgabat earthquake on October 6, 1948 is recorded as one of most destructive earthquake in Turkmenistan. The parameters are as follows, time: 20h 12m 7s GMT, Epicenter: 37.95 NL, 58.32 EL, depth: 18 km, magnitude (MLH): 7.3.
The night from 5 to 6 October in 1948, a strong earthquake occurred in area of Ashgabat. The city and neighboring villages were destroyed in 10-15 seconds. Soil vibrations were so intense that people couldn't stand on their feet, people asleep were falling off their beds, other from their chairs. Railmotor cars were tripped up; cargo train along with its locomotive was thrown off the rails at Gyaurs train station (30 km to the east of Ashgabat).
The earthquake was registered by numerous seismic stations, but all of them were located outside of Turkmenistan. The stations closest to earthquake focus were in Tashkent and Baku. The earthquake was recorded at stations: "Moscov", "Sverdlovsk", "Irkutsk", "Tashkent", "Vladivostok", "Tbilisi", "Yerevan", "Stalinobad", "Alma-ata", "Frunze", "Andijan", "Samarkand", "Baku", "Chemkent" and others.

Photographs of damage due to Ashgabat earthquake in 1948 shows how it was destructive to buildings and infra structures. We can also find a unique scene from the photographs that a high-rise water tower still alive. The quake of the earthquake appears to have destroyed short-period structures.

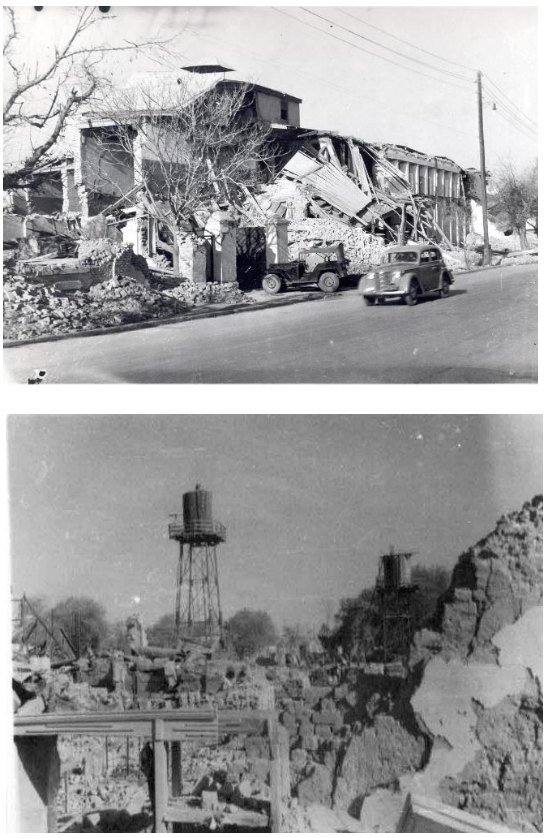


Fig. 2 – Photographs of damage of Ashgabat City due to 1948 Ashgabat earthquake [3]

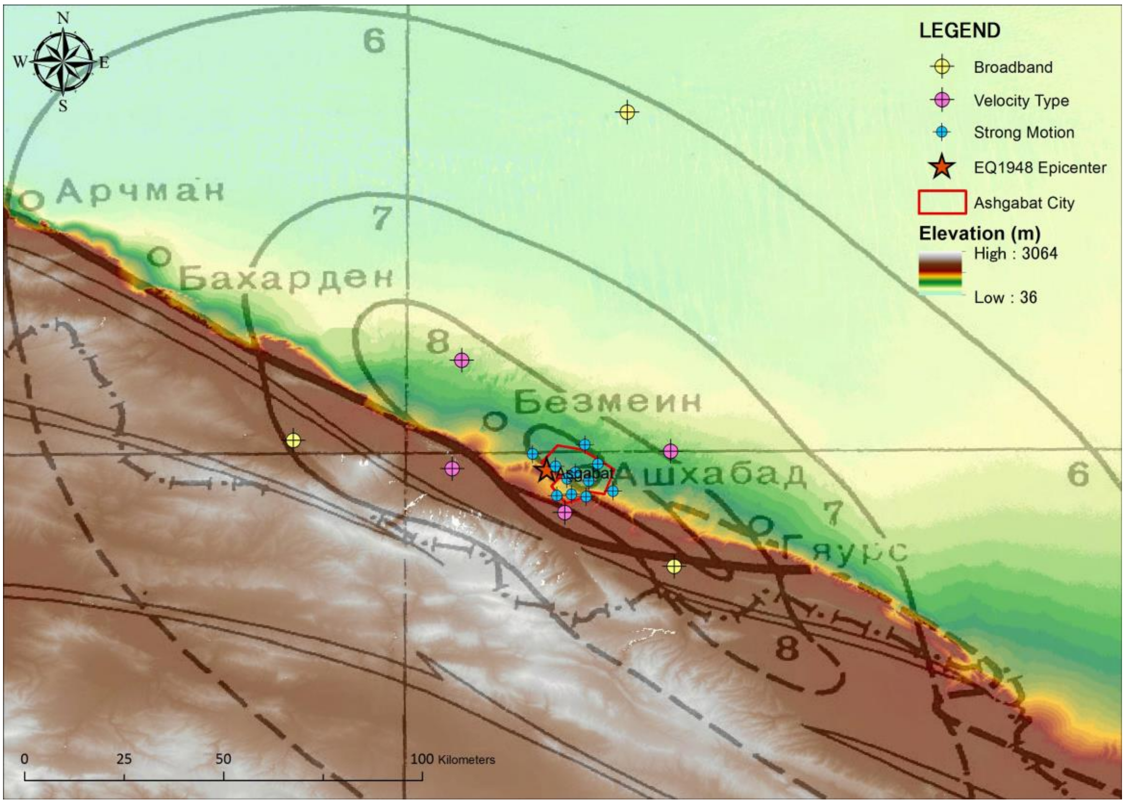


Fig. 3 – Distribution of Seismic intensity of 1948 Ashgabat earthquake [4] and seismograph layout plan

From the point of view to mitigate earthquake damage when Ashgabat earthquake occurs again, the project "Improvement of the Earthquake Monitoring System in and around The Ashgabat City in Turkmenistan" started since 2017 funded by Japan International Cooperation Agency (JICA). First mission is to improve earthquake monitoring system by procuring several kinds of seismographs, including strong motion accelerograph, high-sensitive velocity type seismograph and broadband seismograph. Fig. 3 shows the layout plan of the seismographs overlaying distribution of the MSK-64 intensity during 1948 Ashgabat earthquake [4]. Intensity 9 (and/or more) zone covers Ashgabat City. The preparation of communication networks and housings for those seismographs are going on by the effort of Government of Turkmenistan, which includes satellite communication network system and optic fiber networks.

As basic study in Ashgabat, we had two seminars with the following topics, 1) Introduction of Sendai Framework in October 2017, 2) Introduction of DRR planning methods in October 2018. It would be better to adapt some methods considering Sendai Framework for DRR in Ashgabat City. In some discussion with Prof. Kambod Amini of IISEE at the second seminar we faced important issue that it is very difficult to search and rescue activities in the heavily damaged area due to large earthquake and rescue teams would face difficulties where they should go first. Prof. Nishikawa noted that during the Kobe earthquake 1995 some fire stations were damaged and it was difficult to rush to rescue. Prof. Kato stressed that as a basic information it is necessary to grasp damage estimation of buildings (not only earthquake but also natural multi hazards) and apply to general city planning from large to detailed area.

For such reasons, we reached one methodology that it is necessary to use city planning by controlling building construction by land use restriction to the area where heavily damage were estimated. Fig. 4 shows a figure of draft image of the methodology that in highly hazardous area (i.e. the MSK-64 intensity 10 – 12 areas) would be preferable to conduct response analysis of structures as case study and choose a building design with smaller response displacement. Since the response displacement is expected to vary greatly depending on the building height, it can be said that it is advisable to build a building that takes into account the predominant period of the ground at the site.

The earthquake monitoring system in Ashgabat will store strong motion records to be used to build Ground Motion Prediction Equation (GMPE), especially localized one (e.g. Takai et al. (2015) [5]) is desirable.

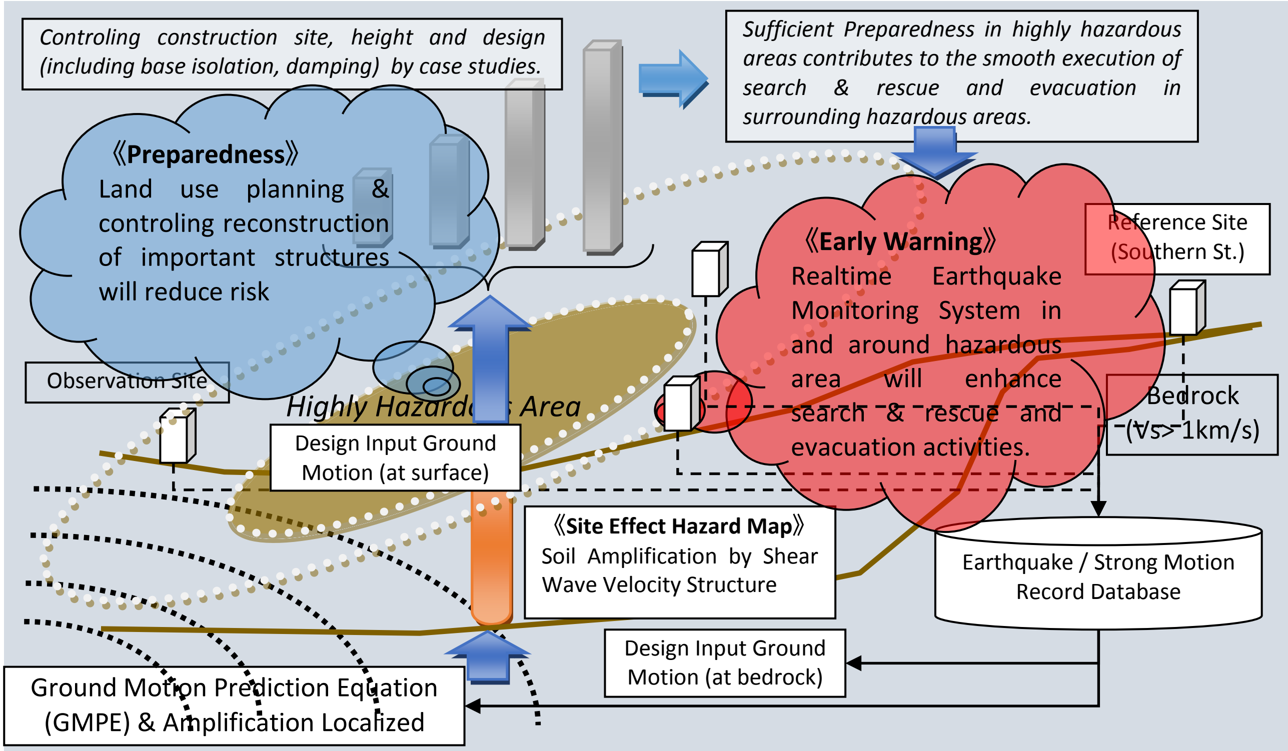


Fig. 4 – Methodology for Disaster Risk Reduction (DRR) Planning

2. Importance of Site Effect

2.1 Shallow S-wave velocity structure by PS-logging

In the project, some geophysical surveys were conducted including PS-logging and array microtremors measurement. The result of measurement is to be summarized into a paper [5]. Fig. 5 shows a cross section lines of Shallow S-wave structure measured by PS-logging at boreholes, which is one of the important result for estimating site effect of ground motion. Fig. 6 shows cross sections of the result of PS-logging and XY graph of average Vs and elevation. Some analysis was added to the basic result of geophysical survey [5]. From the trend of average Vs and elevation, PS logging sites were separated into three, A, B and C. Cross section A shows a trend of fan or natural levee. Cross section C looks like nearly the same location on the map (Fig. 5) However, the trend of B in relation of average Vs to elevation is different from that of line A. It may include hill side sediment so average Vs doesn't increase according to elevation. Cross section C shows another trend which may be hill or mountain side.

Like this way, it is important to classify site effect trends into small zones, so called "microzoning" of site effect.

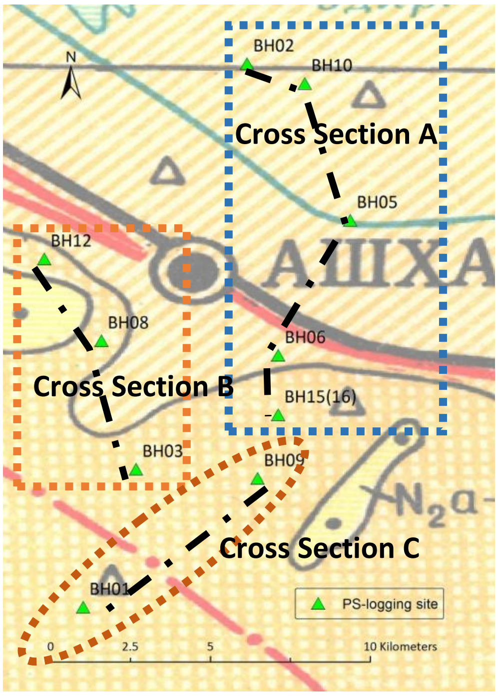


Fig. 5 – Cross section lines to PS-logging sites

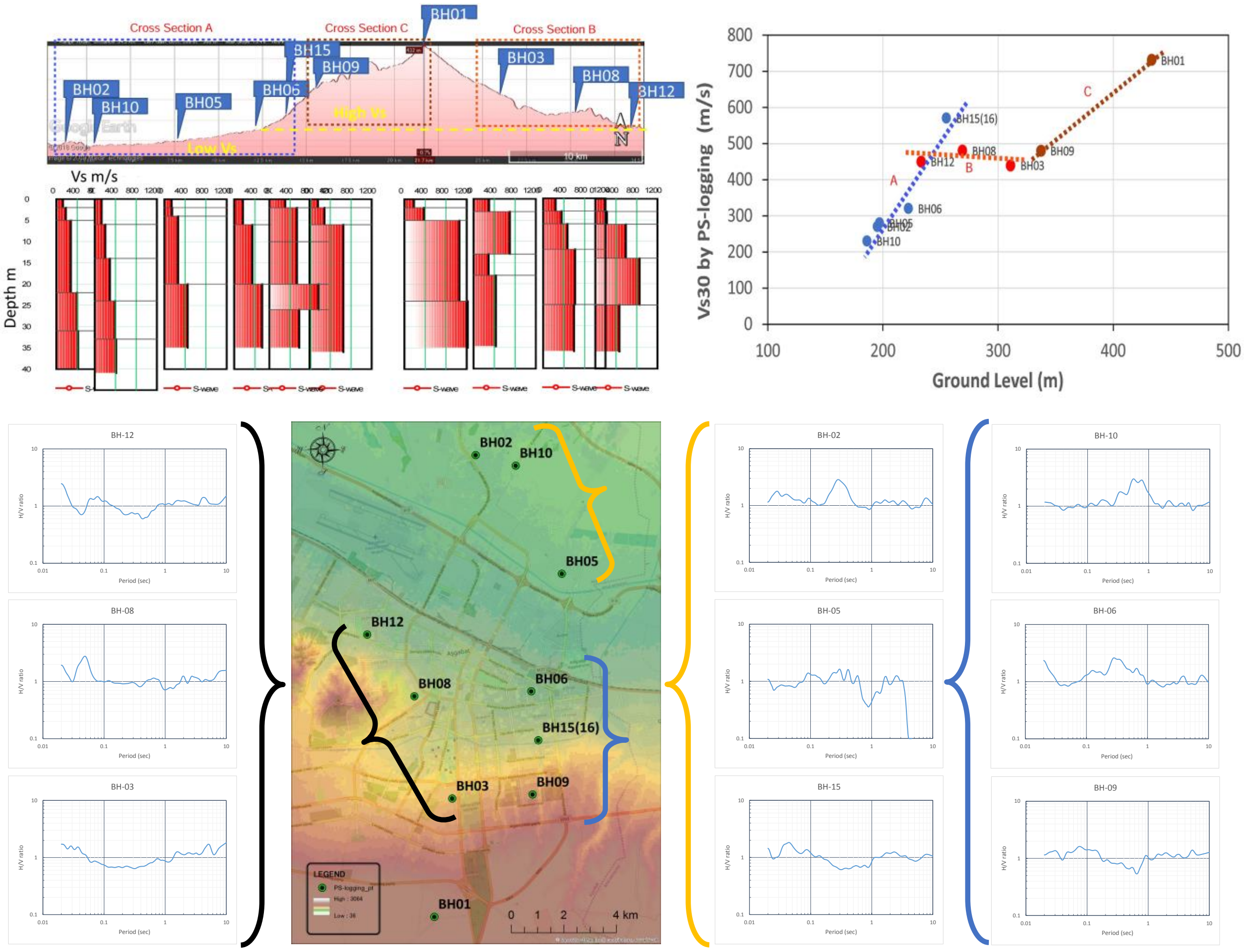


Fig. 6 – Location & Result (Vs structure) of PS-logging in cross section (Upper Left) [6] edited, trend between average Vs and elevation (Upper Right) [6] edited, and H/V spectral ratio at each site (bottom)

2.2 Deep S-wave velocity structure by array mictrotremors measurement

In the project, array microtremors measurement was executed and grasped deep Vs structures up to Vs = 1km/sec, 2 km/sec. Details are to be described in another paper [6]. Here, we will discuss on how to use the result.

If we construct a high-rise building which has more than one second period as first-order natural period, it is necessary to grasp site effect as Fourier spectrum, not single amplification factor. In Japan, For example, Senna (2017) [7] introduces a map of spectral amplification rate at one second period in the whole Kanto region, as a part of activity of National Research Institute for Earth Science and Disaster Resilience (NIED). For this kind of calculation, we need deep Vs structure. His basic idea is to measure array microtremors, estimate deep Vs structure and integrate the result with shallow Vs structure into one Vs structure. He shows one result of calculation on increment of spectral amplification rate at one second period by Haskell's multiple reflection theory. (Fig. 7)

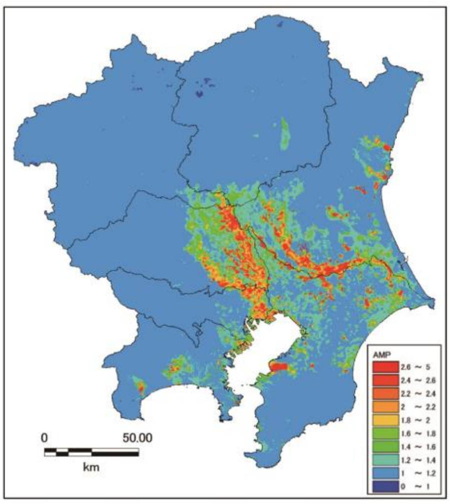


Fig. 7 – Spectral amplification at 1 second period of Fourier spectrum in Kanto region, Japan [7]

3. Site effect by single mictrotremor measurement

3.1 Single microtremors measurement

Omori (1908) [8] started measurement of microtremors and noted that the mean period of micro-tremor of a definite place has a particular value. Kanai et al. (1954) [9] studied the relation curve of frequency-period of micro-tremor and found the curve shows a definite form respective district which is related to geological feature. He also found that the curve has a similarity to that of earthquake motion of near distance from the origin. Based on such general characteristics of microtremors, Kanai and Tanaka (1961) [10] proposed four kinds of ground condition for the Building Code of Japan. Horizontal coefficient of the seismic force in the Code was specified to each kind of ground and to four types of construction; wooden, steel frame, reinforced concrete, and masonry.

Nowadays, spectral ratio of horizontal to vertical (H/V spectral ratio) at single microtremors measurement is well known to predict predominant period and softness of the ground by so many researches, after Nakamura (1986, 1988) [11, 12].

Nogi et al. (2015) studied site classification of NEHRP based on Vs30 in Tohoku and Kanto regions in Japan by comparing microtremors H/V spectral ratios [13]. They showed criteria to classify site effects including category B, C, D and E in NEHRP using average spectral ratio and variance of H/V spectral ratio.

3.2 Analysis of existing single microtremors data

Fig. 8 shows the distribution of single measurement of microtremors by Institute of Seismology, Academy of Sciences of Turkmenistan. The measurement sites are presented in blue dots, and red rectangles are candidates of pilot study area for seismic hazard assessment in this project.

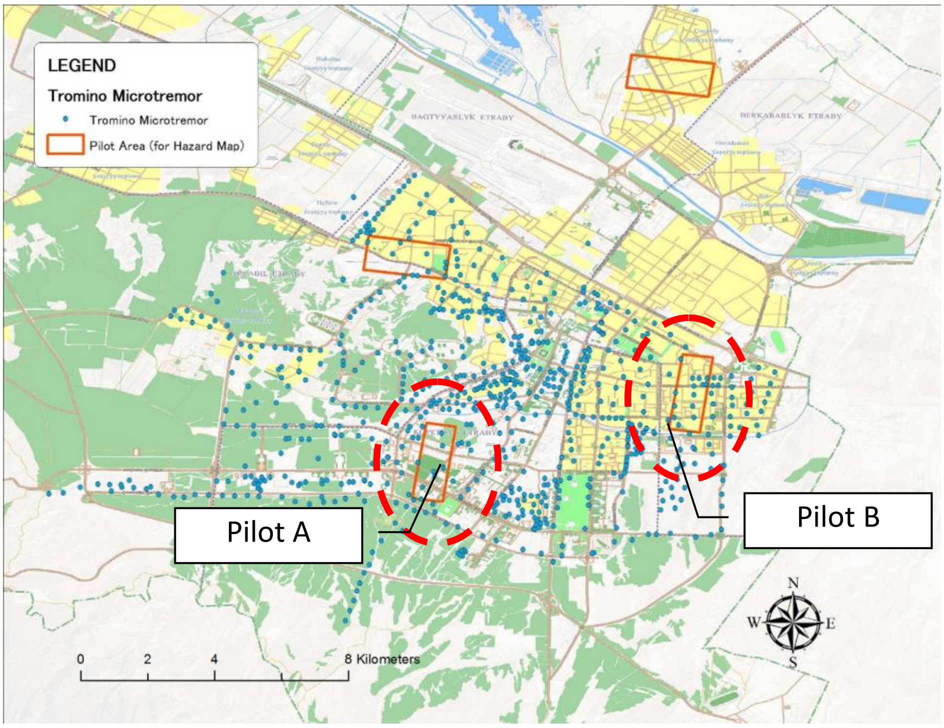


Fig. 8 – Distribution of measurement sites of single microtremors in Ashgabat City

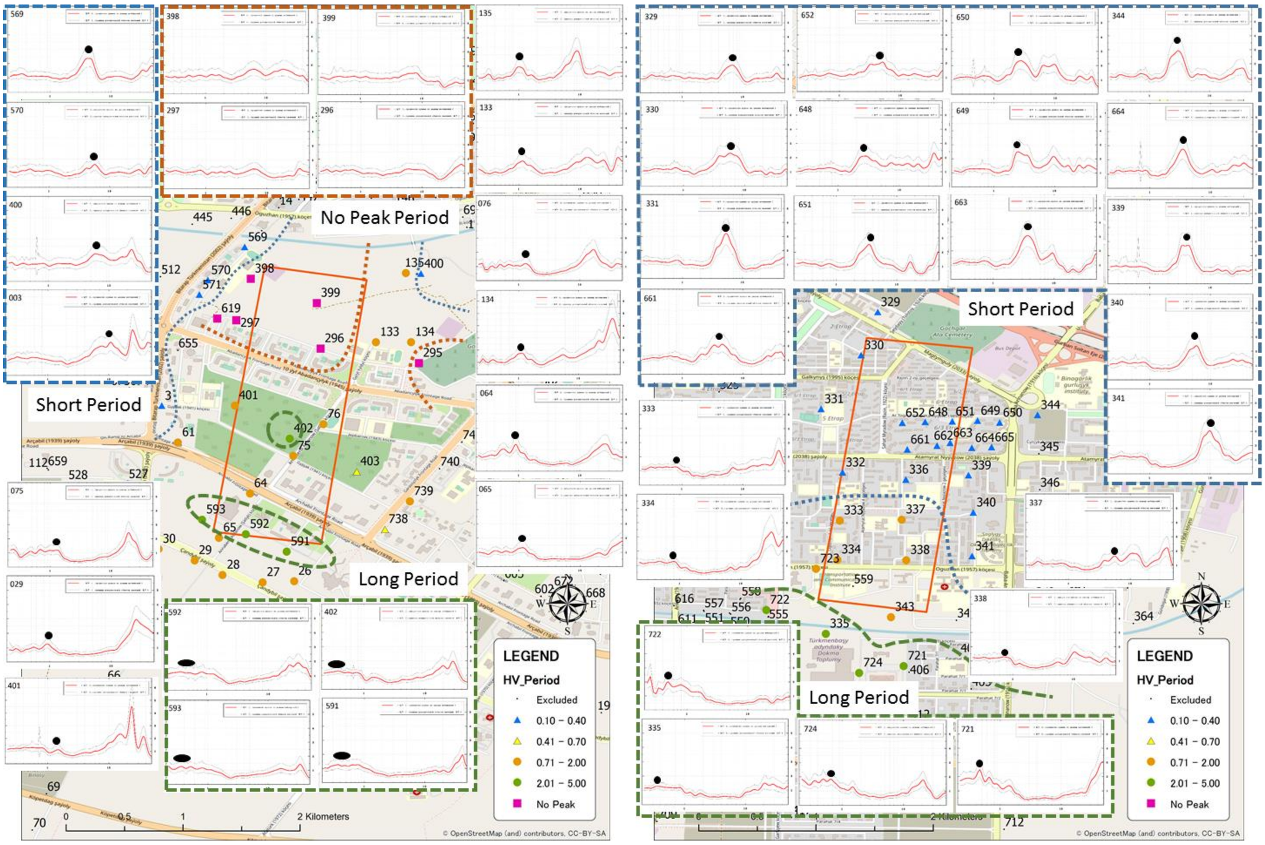


Fig. 9 – Result of interpretation of H/V Spectrum ratio at single microtremors measurement sites in and around pilot area (A: left, B: right)

Some of the H/V spectrum from single microtremors measurement data provided by SI in and around pilot candidate areas were examined especially focusing on predominant period.

After examination, it was found that there was a difference of predominant period and characteristic of H/V spectrum ratio shape, between Quaternary sediment sites and hard rock with shallow sediment ones. Fig. 9 shows the result of analysis for pilot area A and B. The figures includes H/V spectrum ratio to the selected measurement sites to present trend of ground condition. The X axis of H/V spectra is described in frequency scale, from 0.2 to 50 (Hz). The spectrum value in higher than 10 (Hz) was ignored for analysis of sediment soil characteristics due to influence of very shallow surface soil, such as artificial embankment. Predominant period is calculated by dividing predominant frequency.

We classified the predominant period in 0.1 – 0.4 as Short period, 0.4 – 0.7 and 0.7 – 2.0 as two levels of Medium, and more than 2.0 (sec) as Long period. In Fig.9 (left), there is No Peak spectra, which may be explained that there are no sediment soil of Quaternary. It is observed that predominant period distributed in accordance with topographic elevation contour. (Fig.10)

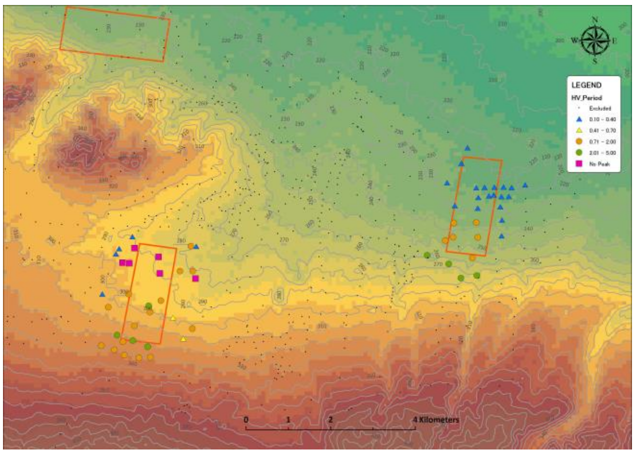


Fig. 10 – Result of interpretation on topographic map

3.3 Ground classification for DRR

One of the simple and important site effect is average S-wave velocity. The most representative of these is the average S-wave velocity up to 30 meters. If it shows a trend of sediment soil layer, we will find some issues at some sites where bedrock reached shallower than 30 meters. This issue is still under consideration.

Fourier spectrum which is calculated from Vs structure must be a better information as a site effect. However, it might be a bit difficult to use it for general users, like planner, architect or administrative officer. Thus it is proposed to adopt predominant period with average Vs for ground classification including site effect. Predominant period reflects a kind of thickness of sediment soil. Average Vs reflect a kind of softness of sediment soil. For example of previous research, Che-Min Lin et al. (2017) introduced depth to the soil layer of Vs 1.0km/sec (Z1.0) and that of 2.5km/sec (Z2.5) in addition to Vs30 for a localized GMPE in Taiwan [14].

As a point of view of DRR planning purpose, ground classification defined by (*Vs*, *T*) seems easy to use. Where *T* is Predominant period of ground, *Vs* is average Vs of sediment soil. Direct Vs value can be obtained from PS logging. Estimated Vs is measured by array microtremors. Single microtremors measurement (H/V spectral ratio) could be used for simple estimation of spatial distribution of predominant period. It is still under consideration how to use several inversion method for Vs structure model from H/V spectral ration.

4. Summary for Challenge to DRR Planning

We'd like to summarize challenge to Disaster Risk Reduction Planning as following,

1) We had a good chance to discuss on DRR planning in one of the technology transfer activities of the project. The project's contents include both real-time earthquake monitoring system and hazard assessment. Just after the earthquake, it is necessary to conduct rescue activities after making decision by administrative organizations based on using real-time information, such as distribution of seismic intensity. Citizens will evacuate according to the decision of the government if their houses are damaged. Improved monitoring will work for this purpose.

2) If the earthquake is so huge and catastrophic, it might be difficult to conduct rescue activities to save all lives from debris of crashed buildings. And citizens could not evacuate from crashed buildings. Even if real-time monitoring system work well for establish initial response system of the government, they might have nothing to do to carry out emergency response activities.

3) To avoid such a situation, it is necessary to conduct hazard assessment. And DRR planning works based on the assessment have to be started. City planning and controlling construction of high-rise buildings are important to reduce earthquake damage of buildings. Especially, the Disaster Response Command Headquarters must survive even in the event of a huge earthquake. For this purpose, considering location based on "microzoning" of site effect would be effective.

4) After the assessment, most destructive zone would be designated as earthquake disaster regulated area. Building construction is to be controlled according to a land use restriction in the area. Land use control has to be based on "microzoning" of site effect. To consider the location of high-rise buildings, it is necessary to consider the ground conditions, "microzoning" of site effect and seismic input source.

5) It is also important to promote the construction of buildings with seismic base isolation and damping structures. High-rise buildings equipped with such latest technology is welcome to be constructed to mitigate earthquake damage. For this purpose, high-rise building design requires structural calculations, especially dynamic analysis. And dynamic analysis requires "design input seismic ground motion".

6) Considering design input seismic ground motion, it is necessary to accumulate strong motion records using the improved earthquake monitoring system by the JICA project. Especially, observation at bedrock site is very important.

7) Business continuity plan (BCP) is also to be considered to survive from earthquake disaster and recover speedily and keep main work in administrative organization and private enterprises.

8) It is important that evacuation drills at the community level be conducted regularly. The target is communities including old residential area of the city and new residential area in the suburbs.

9) Examination by inputting seismic ground motions for designing of high-rise buildings is also important technical issue, as Ashgabat City locates near faults area. As an example, synthetic acceperogram and its response spectrum according to the event on 12/28/2007 is introduced in Fig. 11 [15].

Fig. 12 shows a draft methodology of DRR for Ashgabat City which considers characteristics of type of towns, low-rise houses in new town or old town. Special building control zone is specified to high hazardous area to avoid collapse of buildings in a huge earthquake. This idea is consistent with the promotion of fire prevention measures at each building level (Kato (2018) [16]).

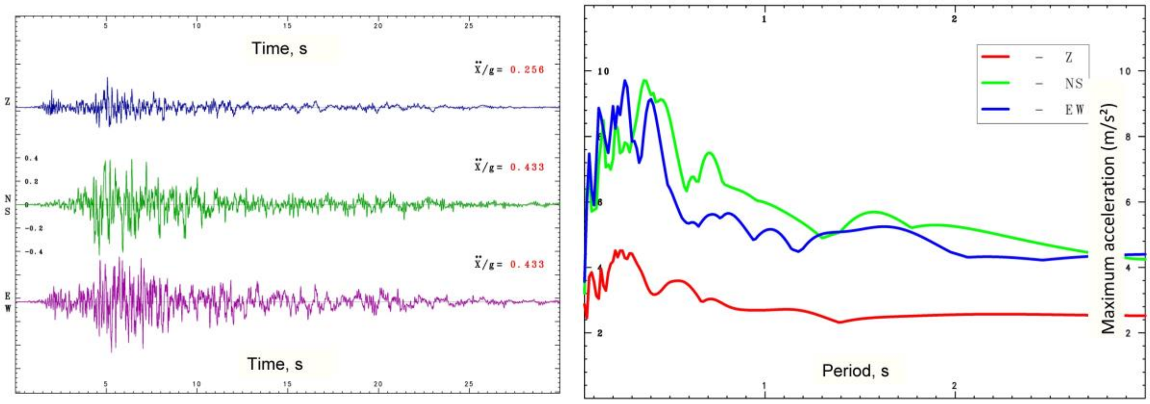


Fig. 11 – A synthetic accelerogram and its response spectrum in the focal area of 1948 Ashgabat earthquake for I=8 (MSK-64) with ground conditions effect on the site at φ = 37.9307833, λ= 58.3673833 degrees in the region str. Atamurat Niyazov. [15]

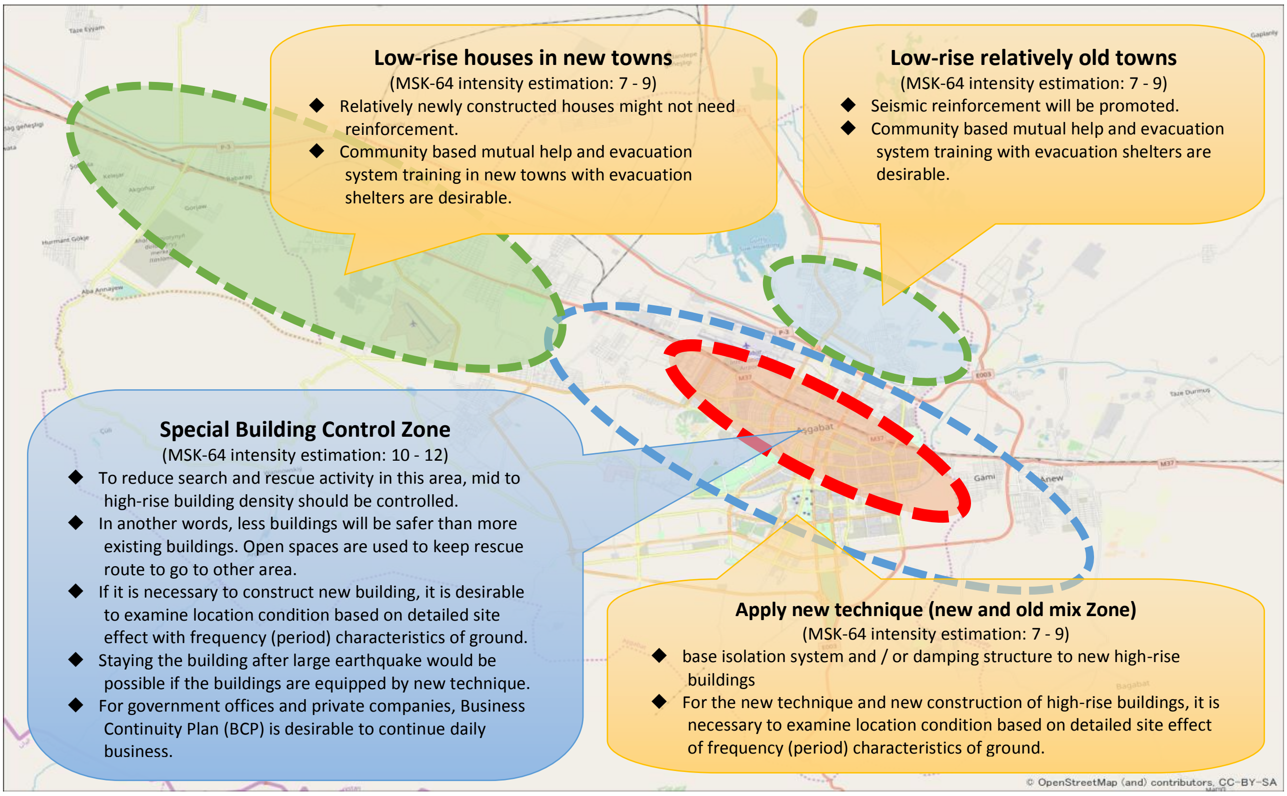


Fig. 12 – Methodology of Disaster Risk Reduction (DRR) Planning for Ashgabat City

5. Conclusion

Several proposal for Disaster Risk Reduction Planning were explained based on the discussion in October 2018 and some progress of the project on analysis of existing microtremors and geophysical measurement. Basic policy was Sendai Framework for Disaster Risk Reduction, which was appealed in the JICA seminar in October 2017. Especially, the discussed methodology on land use planning with controlling construction is related to the global targets following, (a) reduce disaster mortality, (b) reduce number of affected people, (c) reduce direct disaster economic loss and (d) reduce disaster damage to critical infrastructure and disruption of basic services. The main body of the JICA project "improvement of earthquake monitoring system" is also related to (g) increase the availability of and access to early warning systems under the (f) international cooperation.

As a simple summary, it is emphasized that in order to reduce risk in high hazard areas, land use control based on hazard map, especially site effect microzoning. It is much better to promote rebuilding of important facilities by considering construction site selection, case study of seismic response analysis, and with equipped with base-isolation and/or damping system. By reducing risk of collapse of buildings in high hazard areas, early warning and real-time monitoring system will work better for search & rescue activities.

In relatively less hazard areas, seismic retrofitting will be introduced to important facilities for evacuation. Community-based evacuation drills based on hazard map will enhance residents' awareness to disaster reduction. Preparing BCP to private enterprises and government agency will also support emergency response of each organization.

In the seismic structural design of high-rise buildings and seismic base-isolation buildings in Japan, the predominant periods of the design input ground motions are taken into account. According to Eto et al. (2002) [1], in the structural calculation (dynamic analysis) of high-rise buildings & base-isolated structures, it is pointed out that the design fundamental natural period has been set to avoid predominant period of input ground motions. This fact shows how effective it is to design buildings by keeping the fundamental natural period far from those of ground motions.

Ground classification based on predominant period of ground can be examined to determine height of building construction. As it is common that design fundamental natural period has correlation to height of building, the examination and consideration of height of buildings before construction would also be useful for "DRR City Planning".

For further discussion, according to Saitama City [17], Risk of building damages can be monitored using GIS system regularly if Ashgabat City's property tax information system is linked to the DRR Planning System.

As Kanai and Tanaka (1961) [10] proposed classification of ground condition for the Building Code of Japan, it is suggested to create a ground classification by "microzoning" of site effect in Ashgabat City by measuring microtremors. Examination of height of building based on the ground classification can be controlled to mitigate earthquake damage.

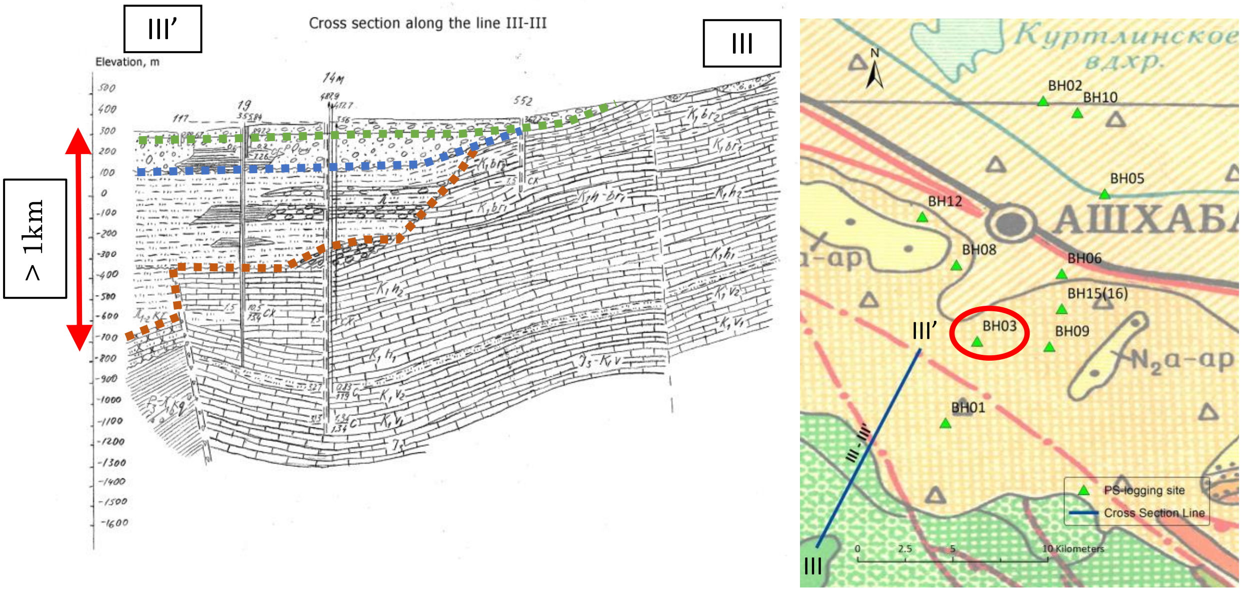
6. Acknowledgements

We would like to express a great appreciation to Dr. Kambod Animi Hosseini, Head of Urban and Regional Planning department, International Institute of Earthquake Engineering and Seismology, Iran for having several important discussion in the seminar at Ashgabat, Turkmenistan in October 2018.

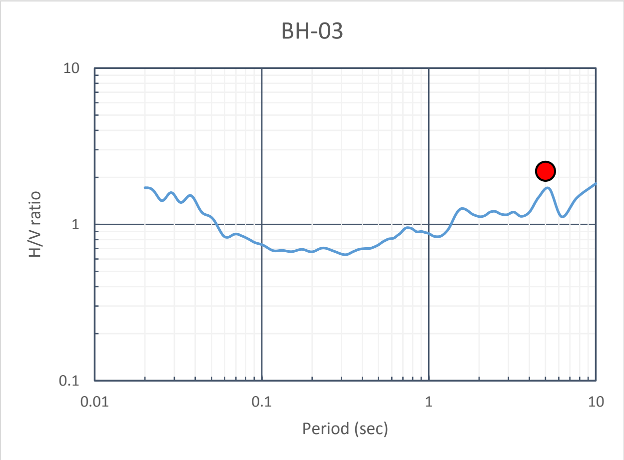
This paper is summarized under an activity of the technology transfer project funded by JICA, named "Improvement of the Earthquake Monitoring System in and around The Ashgabat City in Turkmenistan". I would like to express a great appreciation to JICA for having such opportunity.

7. Notes

* Geological Cross Section and its location on the geological map



(Case Study of estimating thickness of sediment up to bedrock layer, BH-03)



Peak period: 5 sec, Estimated Vs: 1 km/sec (from Array microtremors),

Depth = 1*5/4 = 1.25 km (The depth approximately corresponds to the depth of deepest layer in the above geological cross section.)

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