NUCET NUCLEAR ENERGY AND TECHNOLOGY

Nuclear Energy and Technology 4(4): 251–256
DOI 10.3897/nucet.4.31873

Research Article

Seismic safety evaluation during site selection for the nuclear power plants in Bangladesh*

Ismail Hossain[1], Mohammad Sh. Akbar[2], Vladimir I. Velkin[1], Sergey E. Shcheklein[1]

1 *Ural Federal University named after the 1st President of Russia B.N. Yeltsin, 19 Mira st., Yekaterinburg, 620002, Russia*

2 *Bangladesh Atomic Energy Commission, 4 Kazi Nazrul Islam Avenue, Dhaka-1000, Republic of Bangladesh*

Corresponding author: *Sergey E. Shcheklein* (s.e.shcheklein@urfu.ru)

Academic editor: *Georgy Tikhomirov* ♦ **Received** 3 September 2018 ♦ **Accepted** 20 November 2018 ♦ **Published** 13 December 2018

Citation: Hossain I, Akbar MS, Velkin VI, Shcheklein SE (2018) Seismic safety evaluation during site selection for the nuclear power plants in Bangladesh. Nuclear Energy and Technology 4(4): 251–256. https://doi.org/10.3897/nucet.4.31873

Abstract

Bangladesh lies in a tectonically active zone. Earlier geological studies show that Bangladesh and its adjoining areas are exposed to a threat of severe earthquakes. Earthquakes may have disastrous consequences for a densely populated country. This dictates the need for a detailed analysis of the situation prior to the construction of nuclear power plant as required by the IAEA standards. This study reveals the correlation between seismic acceleration and potential damage. Procedures are presented for investigating the seismic hazard within the future NPP construction area. It has been shown that the obtained values of the earthquake's peak ground acceleration are at the level below the design basis earthquake (DBE) level and will not lead to nuclear power plant malfunctions. For the most severe among the recorded and closely located earthquake centers (Madhupur) the intensity of seismic impacts on the nuclear power plant site does not exceed eight points on the MSK-64 scale. The existing predictions as to the possibility of a super-earthquake with magnitude in excess of nine points on the Richter scale to take place on the territory of the country indicate the necessity to develop an additional efficient seismic diagnostics system and to switch nuclear power plants in good time to passive heat removal mode as stipulated by the WWER 3+ design. A conclusion is made that accounting for the predicted seismic impacts in excess of the historically recorded levels should be achieved by the establishment of an additional efficient seismic diagnostics system and by timely switching the nuclear power plants to passive heat removal mode with reliable isolation of the reactor core and spent nuclear fuel pools.

Keywords

Seismic hazard parameters, IAEA, seismic acceleration and damage, peak ground acceleration

Introduction

Republic of Bangladesh is located within the zone of high geotectonic active region with several seismic events taken place during the extended period of observations in Bangladesh and on the territories of adjoining countries (India, Myanmar, Nepal) (IRIS 2018). Data on the catastrophic increase of seismic activity in this region due to the diastrophic movement of three major tectonic plates – Sunda, Eurasian and Indo-Australian (Michael et al. 2006) – are provided in the papers published during recent years.

Population of Bangladesh reaches 160 million people with extremely low level of per capita electricity consumption, total installed capacity of electric power plants equal to 8.2 GW and annual consumption of electricity

* Russian text published: Izvestiya vuzov. Yadernaya Energetika (ISSN 0204-3327), 2018, n. 3, pp. 30-40.

below 300 kW-hour per capita. Future development of the country depends on the stability of supplies of electricity. Special attention was paid to this problem by the authorities during the last decades. Thus, installed capacity of all energy sources increased from 2010 by practically two times; commissioning of 2 – 3 GW of new thermal power plants was planned in 2016 - 2017; solar energy generation is developing; contracts on import of electricity and liquefied natural gas from adjoining countries are concluded. The targeted indicator here is the increase of capacities to 20 GW by the year 2021.

Nuclear power became the most promising option for Bangladesh because of the possibility of fast commissioning of significant generating capacities, advantages in the solution of environmental protection tasks, financial competitiveness and stability of energy generation (Alam and Islam 2015, Islam et al. 2014). However, construction of large nuclear object on the territory of the country required paying special attention to the investigation of geotectonic environment and use of modern engineering solutions for ensuring its safety.

Rooppur NPP

Rooppur NPP will be constructed on the eastern shore of River Padma in the Pabna District at the distance of approximately 160 km north-west from Dhaka - the capital city of the country. The area of the proposed NPP site amounts to 260 acres and total construction area is approximately 1060 acres.

Nuclear power plant will consist of two power units equipped with WWER-type reactors with power capacity of 1,200MW(e) each manufactured under Russian AES-2006 design and belonging to Generation 3+ nuclear power units with advanced technical and financial performance in correspondence with the most recent reliability and safety requirements. Power units will be equipped with additional passive safety systems not requiring interference of NPP personnel in case of occurrence of emergency situations and preventing their development. The first power unit of the Rooppur NPP is planned to be put into operation in 2023 and the second is scheduled for 2024. Operation life of each of the power units is equal to 60 years. Selection of the Russian design with WWER-type nuclear reactor is explained by the availability of positive experience of operation of such power units on NPPs in Armenia and Iran where reliability of such power units was demonstrated under high levels of seismic impacts (Saakov et al. 2013).

Issues of seismic and nuclear safety are extremely important for Bangladesh, because displacements of ground and vibrations caused by earthquake can lead to damages of equipment and infrastructural objects of the NPP. Earthquake and tsunami caused by it in Japan on the Fukushima-1 NPP prompted investigation of parameters of earthquakes and analysis of results of preceding earthquakes in the republic (Michio et al. 2011, Michael et al. 2008).

Seismic characteristic of the Rooppur NPP site

Geological surveying in Bangladesh and archive information about earthquakes allowed constructing the map

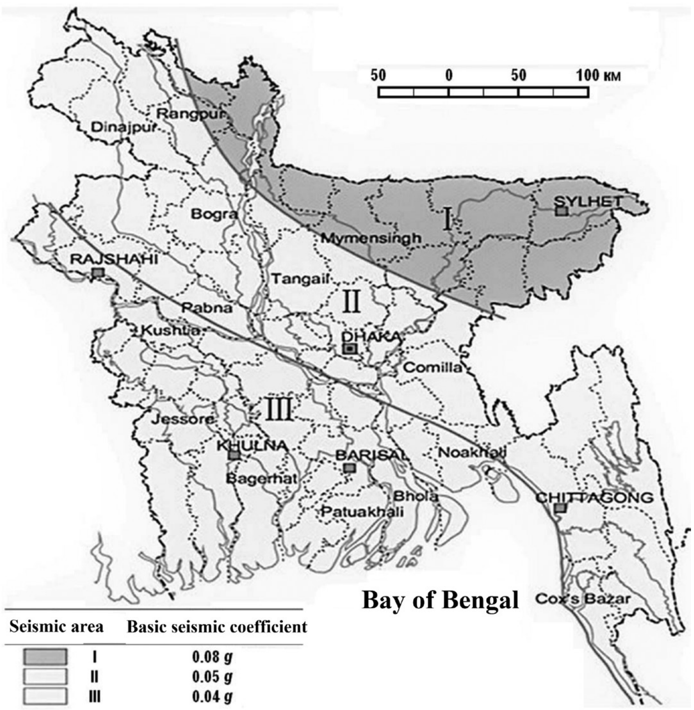

Figure 1. Map of demarcation of macro-seismic regions in Bangladesh

of demarcation of macro-seismic regions of the country. Rooppur NPP construction site is located according to the data of demarcation of macro-seismic regions (Fig. 1) within Zone II with potential peak ground acceleration (*PGA*) up to 0.05g (Anbazhagan et al. 2013).

Despite the favorable enough seismic situation directly on the site selected for NPP construction, significant effect can be produced on the object by earthquakes occurring at significant distances from it.

Characteristics of seismic effects from remote earthquakes

Intensity of effects from remote earthquakes is usually evaluated on the site selected for the construction according to the earthquake intensity scale with subsequent determination of quantitative characteristics of the impact. In correspondence with IAEA recommendations (Manual No. NS-G-2.13 2014, Manual No. NS-G-3.6 2005, Manual No. NS-R-3 (Rev. 1) 2016) and Russian national rules (Birbraer 1998, Ananiev et al. 2011, NP-031-01 2001, RB-06-98 2000, MP 1.5.2.05.999.0025 2011) selection of the site and NPP design must be implemented taking into account two levels of seismic activity: design basis earthquake (DBE) and maximum safe-shutdown earthquake (MSSE). NPP for which safety is ensured for seismic impacts up to MSSE inclusive and output of electricity and heat is maintained up to DBE is regarded as seismically stable. MSSE and DBE are characterized by the number of points, by the set of real analogue or synthesized accelerograms and spectra of reactions modeling main standard types of seismic effects on the NPP site, as well as by main parameters of seismic vibrations: maximum accelerations, period and duration of the phase of intensive vibrations.

Several earthquake intensity scales are used around the world: modified Mercalli scale in the USA, European macro-seismic scale (EMS) in Europe, Japan Meteorological Agency seismic intensity scale (Shindo) in Japan. MSK-64 scale (Medvedev-Sponheuer-Karnik) based on 12 intensity degrees is applied in Russia. Evaluated intensity is somewhat different for seismic scales used in different countries (Brylyova et al. 2011).

It is known that earthquakes with intensity up to four points do not produce significant impact on humans and engineering structures, while humans are practically unable to withstand earthquakes with intensity in excess of 10 points. Ensuring integrity of objects for earthquake intensities from five to 10 points by the use of available engineering solutions is regarded as practically achievable.

The following MSSE and DBE parameters from the nearest seismic areas are determined during the selection of NPP site: magnitude, depth of earthquake source, distance to the seismogenic area and the degree of seismic activity on the MSK-64 scale on the standard ground on the site, seismic activity in case of MSSE and DBE expressed in points for the site of the NPP reactor room, maximum amplitudes of horizontal oscillations on the free surface of the site planned for the reactor compartment for MSSE and DBE conditions – accelerations (cm/c^2) and velocities (cm/s), maximum amplitudes of horizontal oscillations of the roof of rock formation stratum; period of maximum amplitude of the acceleration (accelograms) and velocity (velocitograms) at the planning level for MSSE, ratio of vertical acceleration to the horizontal acceleration, etc.

Methodology of evaluation of seismic impact

Intensity of seismic impact in MSK-64 scale points and dynamic characteristics on the NPP site in the form of response accelograms calculated according to the experimentally obtained seismograms for the most severe earthquake among all registered earthquakes were determined depending on the earthquake force characterized by magnitude, depth of the earthquake hyprocenter (focus), properties of the ground and distance to the NPP. Typical schematics of deep-focus earthquake characteristic for Bangladesh conditions is presented in Figure 2.

The following was determined as the result of calculation:

- *PGA* – horizontal component of the peak ground acceleration in cm/c^2 or in fractions of g having the highest value for forecasting potential destruction of objects;
- Earthquake intensity, which is determined in points on the MSK-64 macro-seismic scale;
- Dynamic characteristics of the impact in the form of accelograms, velocitograms and the diagram of response displacements on the NPP site for minimal damping coefficient equal to 5%.

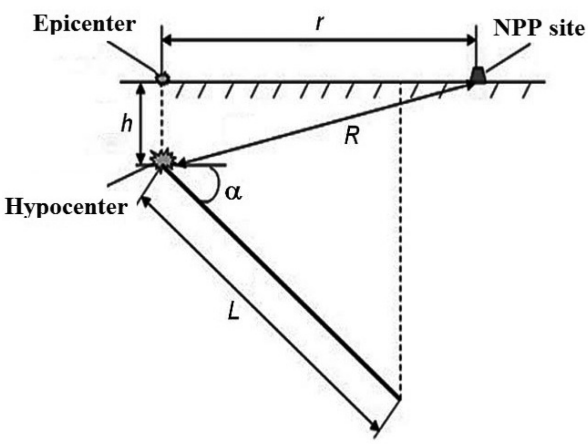

Figure 2. Calculated schematics of deep-focus earthquake: h is the hypocenter depth, km; L is the fault line length, km; α is the incidence angle, degrees; r is the distance to the NPP, km; R is the hypocentral distance to the NPP, km

Horizontal component of the peak ground acceleration

According to the data in (Bari and Das 2014, Duggal 2007), the most accurate results for the *PGA* determination are obtained from the Dougall equation:

$$PGA = 227.3 \cdot 10^{0.308M} (r + 30)^{-1.201}, \text{ cv/c2} \quad (1)$$

where M is the earthquake magnitude on the Richter scale; r is the epicentral distance, km.

Earthquake intensity

Empirical relations between I, magnitude M and the distance to the focus for basic (standard) ground (Birbraer 1998) are used in the evaluations of intensity:

$$I = \alpha \cdot M - \gamma \cdot \lg R + c \quad (2)$$

where M is the earthquake magnitude on the Richter scale; $R = (r^2 + h^2)^{1/2}$ is the hypocentral distance, km; $\alpha = 1.5$, $\gamma = 3.5$, $c = 3$ are the coefficients for basic (standard) ground.

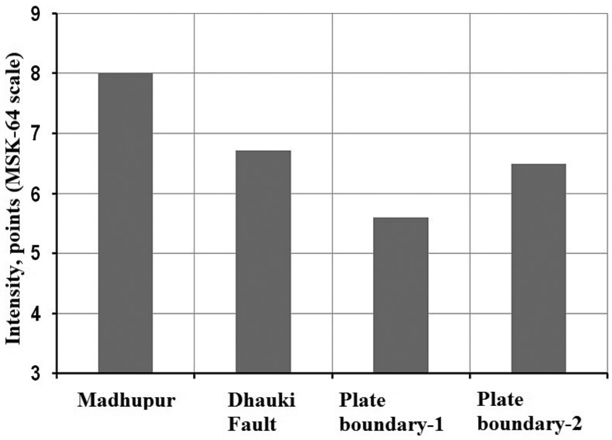

Figure 3. Intensities of seismic impact on the Rooppur NPP site depending on the initiating event

Characteristics of earthquakes

Characteristics of the most severe earthquakes for which the data of instrumental measurements are available (IRIS 2018, Michio et al. 2011) are presented in Table 1.

Results of calculation study

Values of macro-seismic characteristics for the location of the Rooppur NPP site calculated according to the data in Table 1 are presented in Table 2.

Data on the intensity of seismic impact for the location of the Rooppur NPP site are presented in Figure 3 depending on the initiating event.

It is evident from the Figure that even for the most severe of the registered and closely located earthquake centers (Madhupur) intensity of seismic impact on the NPP site does not exceed eight points on the MSK-64 scale.

Experimental seismic records of the earthquake are presented in Figure 4.

It is clear that the amplitude of seismic impact for the levels of the surface, base and rock exposure is conservative enough. However, certain transformation of the frequency structure of the process takes place with attenuation of short-period oscillations with depth.

The data on the calculation of response to the seismic impact in the form of accelogram, velocitogram and displacement diagram on the NPP site for damping coefficient equal to 5% corresponding to the absence of special requirements on seismic protection, are presented in Figure 5.

It is evident that the largest impacts on the NPP site are within the range of periods of ground oscillations of 0.1 – 10 seconds with peaks of acceleration with the range of 0.8 – 2 c, peaks of velocities within the range from 2 to 3

Table 1. Characteristics of the most severe earthquakes in Bangladesh

Focus	PGA (g)	*h* – hypocenter depth, km	*L*- fault line length, km	*α* – incidence angle	*r* – distance to the NPP, km
Madhupur	0.210646	10	60	45	42
Dhauki Fault	0.083747	3	233	60	43
Plate boundary - 1	0.030249	3	795	20	377
Plate boundary - 2	0.071503	3	270	30	137

Table 2. Values of macro-seismic characteristics for the location of the Rooppur NPP site

Focus	*M* – magnitude on the Richter scale	*I* – points, calculation according to (2)
Madhupur	7.5	8
Dhauki Fault	8.0	6.7
Plate boundary - 1	8.5	5.6
Plate boundary - 2	8.0	6.5

s and peak for displacements within the range from 2 to 8 s which proves low-frequency nature of the impact on the objects located on the site and determines selection of adequate design and engineering compensating measures (ensuring strength of elements of fuel assemblies, reactor CPS control elements and drives in accordance with regulations; ensured possibility of unhindered drop of CPS absorbing rods along the guiding channels of fuel assemblies for reactor shutdown after safety tripping; introduction of control elements of the reactor CPS in the reactor core within the time limits stipulated in the reactor design; ensuring the possibility of unloading reactor core; solid basement plate of the reactor facility; expanded safety margins for pipelines and equipment, seismic amortization protection of equipment, etc.) (Makarov et al. 2011).

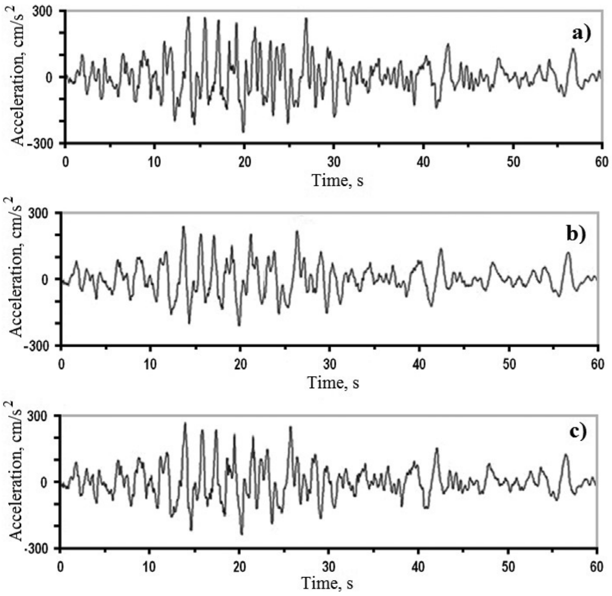

Figure 4. Seismic record of the Madhupur earthquake: a) – surface; b) – base; c) – rock exposure

Discussion

Results of demarcation of seismic regions on the Bangladesh territory (see Fig. 1) and data on the calculation of seismic impacts from remote earthquakes on territories of Bangladesh and neighboring countries demonstrate (see Table 2, Figs. 3 – 5) that maximum seismic impact on the NPP and its equipment will not exceed eight points on the MSK-64 scale. Achieving the required level of NPP safety for the case of design basis earthquake equal to seven MSK-64 points can be ensured through the use of already available engineering solutions aimed at the enhancement of seismic stability (industrial seismic protection systems – ISPS) implemented in Russian AES 2006 NPP design projects (and subsequent modifications) which include in their composition seismic sensors arranged on the foundation plate of the reactor facility (RF) intended for continuous control of seismic impacts on the NPP RF and shaping discrete signal indicating the exceedance over the established threshold of ground oscillations.

Existing forecasts of the possibility of occurrence on the territory of the country of super-earthquake with magnitude in excess of nine points on the Richter scale indicate the necessity of development of additional efficient seismic diagnostics system and timely transition of the NPP to the passive heat removal mode as stipulated in the WWER 3+ design and is further elaborated in (Galiev et al. 2017).

Thirty years of experience of operation on the territory of the country of the research TRIGA reactor (3 MW) demonstrated practical possibility of safe operation of nuclear hazardous objects in the Bangladesh conditions.

Conclusion

1. Construction of the Rooppur NPP is the only way for radical improvement of energy supplies in Bangladesh within the shortest timeframe.
2. Russian WWER 3+ design possesses all the components necessary for ensuring efficient seismic protection of NPP equipment and allows ensuring safe operational conditions in real seismic environment.
3. Taking into account the forecasted seismic impacts in excess of historically registered levels must be ensured by the development of additional efficient seismic diagnostics system and timely transition of the NPP into

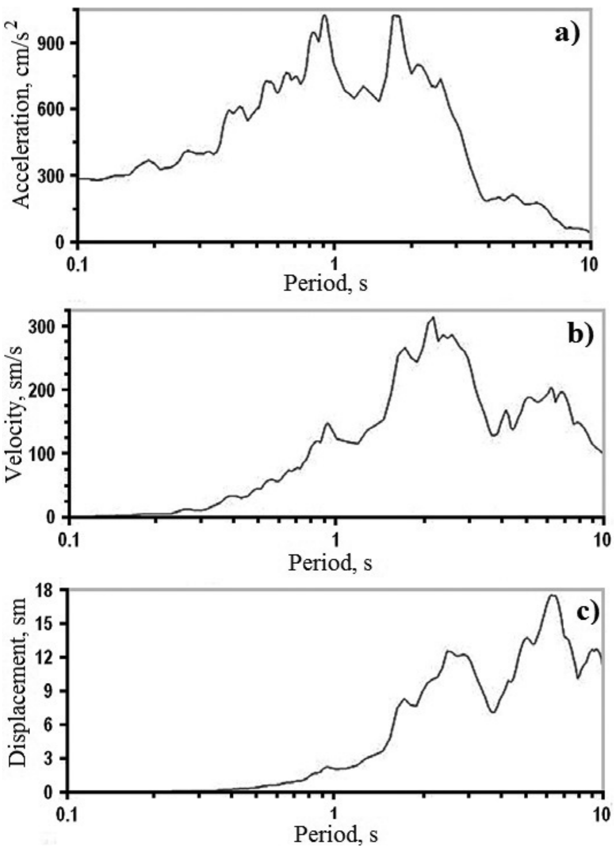

Figure 5. Response accelogram (a), velocitogram (b) and displacement diagram (c) on the NPP site (damping coefficient is equal to 5%)

passive heat removal mode with reliable isolation of the reactor core and spent nuclear fuel pools.

The present study was performed under the RF Government Decree No. 211, Contract No. 02.A03.21.0006.

References

- Alam MT, Islam MR (2015) A Paradigm Shift in Bangladesh Energy Sector towards SDG-7: A Few Insights of Energy Statistics in Bangladesh. Incheon, South Korea: 1-50.
- Ananiev AN, Kazanovski PS, Kazanovski SP, Lebedev VI, Chechenov KD (2011) Seismic safety of nuclear power plants. Moscow, MGTU n.a. Bauman Publ., 234 pp. [in Russian]
- Anbazhagan P, Smith CV, Abishek K, Deepu C (2013) Estimation of design basis earthquake using region specific Mmax for the NPP site at Kalpakkam, Tamil Nadu, India. Nuclear engineering and Design, 259: 41-64. https://doi.org/10.1016/j.nucengdes.2013.02.047
- Bari MdS, Das T (2014) A comparative study on seismic analysis of Bangladesh National Building Code (BNBC) with other Building codes. Journal of the Institution of Engineers (India): Series A, 94 (3): 131-137.
- Birbraer AN (1998) Calculation of Structures for Earthquake Resistance. SPb., Nauka Publ., 225 pp. [in Russian]
- Brylyova VA, Voitetskaya EF, Nareyko LM (2011) The main characteristics of earthquakes. Belorussian Academy of Sciences. Inf. Bull. “OIAE i YaF-Sosny”, Ser.: Atomnaya Energetika, 1-2: 1-10 [in Russian]
- Duggal SK (2007) Earthquake resistant design of structures. Oxford University Press, 448 pp.
- Galiev II, Chernyaev AN, Bibik SV (2017) Development of seismic protection system for design extension conditions. Izvestiya vuzov. Yadernaya Energetika, 4: 94-112. [in Russian]
- Hossain I, Akbar MS, Rahman A (2014) Thesis-Nuclear power plant pre design documentation: seismic and flooding hazard evaluation. Dhaka University Library: 53-77.
- IRIS (2018) Incorporated Research Institutions for Seismology. Available at: http://www.iris.edu [accessed May 05, 2018]
- Islam A, Chan ES, Taufig-Yap YH, Mondal MAH, Moniruzzaman M, Mridha M (2014) Energy security in Bangladesh perspective – An assessment and implication. Renewable and Sustainable Energy Reviews, 32: 154-171. https://doi.org/10.1016/j.rser.2014.01.021
- Makarov VV, Afanasiev AV, Matvienko IV, Dolgov AB (2011) Tests of TVS-square mock-ups of fuel assemblies of NPP-2006 with drive of CPS SheM-3 for seismic actions. 7-th MNTK “Safety of NPP with WWER”, Podolsk, Russia. 17-20 May 2011. OKB “GIDROPRESS” Publ.: 1-12. [in Russian]
- Manual No. NS-G-2.13 (2014) IAEA Safety Standards Series. Estimation of seismic safety of existing nuclear installations. IAEA, Vienna: 1-76. [in Russian]
- Manual No. NS-G-3.6 (2005) Geotechnical aspects of assessments for NPP sites and foundations. IAEA Safety Standards Series. IAEA, Vienna: 1-58. [in Russian]
- Manual No. NS-R-3 (Rev. 1) (2016) Assessment of sites for nuclear installations. IAEA Safety Standards Series. IAEA, Vienna: 1-31. [in Russian]
- Michael SS, Akhter SH, Seeber L (2008) Collision of the Ganges-Brahmaputra Delta with the Burma Arc: Implications for earthquake hazard. Earth and Planetary Science Letters, 273(15), iss. 3-4: 367-378.
- Michael SS, Mondal DR, Akhter SH, Seeber L, Feng L, Gale J, Emma MH, Michael H (2006) Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges. Nature Geoscience, 9: 615-618.
- Michio M, Maksud Kamal ASM, Dicky M, Reshad MEA, Mohammad AK, Rahman MZ, Fumio K (2011) Seismic event of the Dhauki Fault in XVI century confirmed by trench investigation at Gabrakhari Village, Haluaghat, Mumensingh, Bangladesh. Journal of Asian Earth Sciences, 42: 492-298. https://doi.org/10.1016/j.jseaes.2011.05.002
- MP 1.5.2.05.999.0025 (2011) Calculation and design of earthquake resistant nuclear power. Saint Petersburg, OAO “Kontsern Rosenergoatom” Publ., 140 pp. [in Russian]
- NP-031-01 (2001) Norms of designing seismic resistant nuclear power plants. Moscow, Gosatomnadzor Rossii Publ., 27 pp. [in Russian]
- RB-06-98 (2000) Determination of initial seismic vibrations of soil for project bases. Moscow, Gosatomnadzor Rossii Publ., 76 pp. [in Russian]
- Saakov AC, Ryasni CI, Kaznovski PS, Kasyanov KG, Emelyanova AD (2013) Comparative analysis of foreign and Russian methodologies for assessing seismic resistance of nuclear power plant equipment. Atomnaya Energiya [Atomic Energy], 115(6): 309-317. [in Russian]