doi: 10.18720/MCE.75.13

Modeling the design seismic input in conditions of limiting seismological information

Моделирование расчетного сейсмического воздействия в условиях ограниченной сейсмологической информации

T.V. Ivanova,
"B.E. Vedeneev VNIIG", JSC, Saint Petersburg, Russia
J. Guan,
O.P. Nesterova,
S.V. Prokopovich,
Petersburg State Transport University, St. Petersburg, Russia
L.N. Smirnova,
JSC Research Center of Construction, Moscow, Russia,
A.M. Uzdin,
Petersburg State Transport University, St. Petersburg, Russia
D.A. Ivashintzov,
"B.E. Vedeneev VNIIG", JSC, Saint Petersburg, Russia

Канд. техн. наук, ученый секретарь Т.В. Иванова,
АО "ВНИИГ им. Б.Е. Веденеева", г. Санкт-Петербург, Россия
аспирант Ю. Гуань,
аспирант О.П. Нестерова,
аспирант С.В. Прокопович,
Петербургский государственный университет путей сообщения Императора Александра I, г. Санкт-Петербург, Россия
канд. техн. наук, ученый секретарь Л.Н. Смирнова,
АО «Научно-исследовательский центр «Строительство», г. Москва, Россия
д-р техн. наук, профессор А.М. Уздин,
Петербургский государственный университет путей сообщения Императора Александра I, г. Санкт-Петербург, Россия
д-р техн. наук, гл. науч. сотрудник Д.А. Ивашинцов,
АО "ВНИИГ им. Б.Е. Веденеева", г. Санкт-Петербург, Россия

Key words: seismic input; input characteristics; peak ground acceleration; harmonious ratio; Arias intensity; cumulative absolute velocity; seismic energy density

Ключевые слова: сейсмическое воздействие; генерация воздействия; характеристики землетрясения; пиковые ускорения основания; коэффициент гармоничности; интенсивность по Ариасу; кумулятивная абсолютная скорость; плотность сейсмической энергии

Abstract. The object of the investigations is seismic input models used in structure designing under the conditions of limited seismological information. The aim of the given investigation is to propose a new variant of a seismic input model, which should be generated for the structure under consideration, taking into account main peculiarities of actual seismic excitations. The method of design seismic input generation by means of its presentation as a sum of velocity impulse and multi frequency excitation has been developed. The duration and peak value are parameters of velocity impulse. They can be presented as function of possible earthquake magnitude and hypocentral distance. Multi frequency excitation can be presented as a product of sinusoid and some envelope function. Parameters of the impulse and multi frequency excitation are determined to provide accordance of generated input characteristics with characteristics of past earthquakes. Characteristics of past earthquakes were estimated using the joined database including more than 100 records of strong earthquakes presented by Chinese and Russian experts.

Аннотация. Предмет исследований – модели сейсмических воздействий, используемые при проектировании сооружений в условиях ограниченной сейсмологической информации. Цель выполненного исследования – предложить новый вариант модели сейсмического воздействия, которая должна генерироваться для рассматриваемой конструкции с учетом основных особенностей реальных сейсмических воздействий. Развит метод генерации расчетного сейсмического воздействия, использующий его представление в виде суммы импульса скорости и

Иванова Т.В., Гуань Ю., Нестерова О.П., Прокопович С.В., Смирнова Л.Н., Уздин А.М., Ивашинцов Д.А. Моделирование расчетного сейсмического воздействия в условиях ограниченной сейсмологической информации // Инженерно-строительный журнал. 2017. № 7(75). С. 129–138.

полигармонического возмущения. Параметрами импульса скорости являются его продолжительность и пиковое значение. Они могут быть представлены как функции возможной магнитуды землетрясения и гипоцентрального расстояния. Полигармоническое возмущение представляет собой произведение синусоиды на некоторую огибающую. Параметры импульса и полигармонического воздействия определяются так, чтобы характеристики сгенерированного воздействия соответствовали натурным характеристикам прошлых землетрясений. Характеристики реальных воздействий оценены с использованием общей базы данных российских и китайских специалистов, включающей более 100 записей 9-ти бальных землетрясений.

Introduction

At present two models of seismic input are used in earthquake engineering practice [1]. The first model is based on generating the input for the building site, and the second model is based on generating the input for structure. There is also a group of intermediate models in which the input is generated for a given response spectrum. If this spectrum is set for a building site, then these models belong to the first group and if the spectrum is given for a construction, then they belong to the second group. Finally, the spectral curve of Guidelines can be taken as the spectrum. Then the input model will have all the errors inherent in the normative spectral curve. This question was discussed in detail in [2, 3].

Input models for the building site were built by many experts [5–11]. These models are advanced by seismologists and require seismological information for the building site. Although this approach to generating the input seems quite logical, it raises some objections from engineers.

First, in engineering practice, the necessary seismological information is not always available. Generally it is used in designing nuclear power plants and large dams. Even in designing the world largest cable-stayed bridge across the Easten Bosporus to the Russian Island, there was no complete seismological information, and when designing transport Olympic facilities in Sochi, the necessary information had been received only by the end of the designing process, when all design decisions have been made.

Secondly, building engineers do not always trust seismological information. This is due to the fact that out of 27 strong earthquakes that have been place in the former USSR since 1948, 24 occurred in areas previously considered to be non-seismic or weakly seismic.

Thirdly, structures can be rather sensitive to small changes in the response spectrum. Sometimes, a 5% change in the input prevailing period of the spectrum, which is quite possible within the framework of seismological studies, leads to a twofold change of seismic loads. Metal structures are particularly sensitive to these changes.

Fourthly, the generation of input for the building site is completely unfit for a typical designing, when the structure is to be earthquake-proof on any sites.

It is these shortcomings that led to the development of input models with a spectrum that repeats the normative spectral curve. It should be noted here that for the given spectrum one can generate infinitely many inputs [1, 8]. Besides it should be capped in mind the normative spectral curve itself contains errors which in the Guidelines are balanced by errors in specifying the design peak accelerations and errors in the damping task [1, 2], but not balanced in design accelerograms. For these reasons, this approach can lead to unpredictable results.

An alternative to generating input for the building site is the second model of seismic input, i.e. generation of input for the construction. In this case, the properties of the building site are ignored completely or partially, and the most hazardous input is determined for the structure. For linear structure models, the input model is given as a resonant one for the structure. For structures in the inelastic stage of behavior, dangerous input frequencies are determined iteratively. This process is described, for example, in [12].

The aim of the given investigation is to propose a new variant of a seismic input model, which should be generated for the structure under consideration, taking into account main peculiarities of actual seismic excitations.

The authors develop a well-known approach to the generation of seismic input for structures used for a standardized design, when the structure must be earthquake-proof on any site with a given seismicity [1, 11]. In the proposed version of the method, it is possible to take into account some seismological features of the building site. First of all, it is situational seismicity determined by using general seismic zoning maps and Guidelines in law [13]. Information about possible sources of earthquakes is often available and one can take into account the possible magnitude and hypocentral distance for the structure under consideration. These data had been available, for example, in [14].

Methods

Description of the input model.

In this investigation the authors set the predominant input frequencies equal to the eigen structure ones. It makes the input dangerous for the structure under consideration. Other input parameters are indefinite ones and can be set by the way of providing the correspondence of the input model to actual earthquakes. The design input is represented as the sum of the speed pulse and the polyharmonic process, as it was used in [15].

In this case the input velocigram is written in the form

$$\dot{y}_0 = V(t-\phi)\cdot\eta(t-\phi) + \sum_{i=1}^{3} a_i e^{-\alpha_i t}\left(1 - e^{-\beta_i t}\right)\sin\omega_i t \quad (1)$$

,

where V (t) is the velocity impulse separated out the seismic input,

ϕ is phase shift from the beginning of the earthquake to the moment when the speed pulse arrives to the structure;

H (z) is the Heaviside function;

a_i, α_i, β_i and ω_i are the parameters of the polyharmonic component of the process.

The velocity pulse is described by the following dependences of the acceleration *acc*, the velocity v, and the displacement u on time

$$acc(t) = \begin{cases} u_{max}/t_0^2 \\ -u_{max}/t_0^2 \\ 0 \end{cases} \qquad v(t) = \begin{cases} u_{max}\, t/t_0^2 \\ \dfrac{u_{max}}{t_0}\left(2 - \dfrac{t}{t_0}\right) \\ 0 \end{cases} \qquad u(t) = \begin{cases} \dfrac{u_{max}}{2}\left(\dfrac{t}{t_0}\right)^2 \\ \dfrac{u_{max}}{2}\left[-\left(\dfrac{t}{t_0}\right)^2 + 4\cdot\left(\dfrac{t}{t_0}\right) - 2\right] \\ u_{max} \end{cases}. \quad (2)$$

Graphical interpretation of expressions (2) is presented in Figure 1.

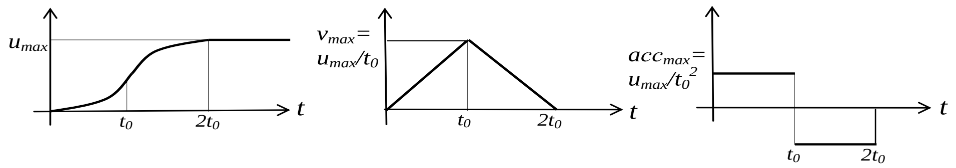

Figure 1. Time charts of displacements, velocities and accelerations for the speed pulse

The presence of a velocity pulse in a seismic input was fined by Italian seismologists [16]. They obtained the relationship between the pulse parameters and the magnitude of the earthquake Mw and the hypocentral distance R.

In particular, the half-pulse duration t_0 is uniquely determined by the magnitude of the action

$$t_0 = 10^{\left(-3.471 + 0.5\cdot M_w\right)}; \quad (3)$$

And the residual displacement of the action depends on the magnitude and hypocentral distance

$$u_{max} = 10^{\left(-6.3 + M_w - \ell og(R)\right)} \quad (4)$$

In this case, the velocity pulse is represented in the accelerogram as a step with an amplitude

$$acc_{max} = \frac{u_{max}}{t_0^2} = \frac{4.35}{R} \quad (5)$$

In formulas (3–5), obtained in [16], the value of R is substituted in "km", and the displacements, velocities and accelerations are obtained respectively in "m", "m/s" and "m/s^2". It is shown in [17] that the velocity pulse, theoretically obtained in [16], is presented in real accelerograms. This allows us to consider the input model in the form (1), as sufficiently universal. It has 12 indeterminate parameters: three parameters determining the momentum of the speed (Mw, R and ϕ) and 9 parameters (a_i, α_i, β_i, i=3) defining the polyharmonic process. Frequencies ω_i are set hazardous for the structure. Undefined parameters are set so that the accelerogram model has properties of real accelerograms. This statement of the problem is available in the works of A.A. Dolgaya [18, 19]. In the works mentioned, the input model was brought to conformity with real peak ground accelerations and Arias intensity. These proposals were included in the Recommendation [11]. Below they are developed taking into account new data about past earthquakes.

The main characteristics of seismic input

Three types of real accelerograms characteristics are distinguished in the literature [1, 20]: kinematic, spectral and energy.

The kinematic characteristics include peak accelerations (PGA), peak velocities (PGV), maximum displacements, residual displacements y_{rez}, duration of the action τ_{eq}, and also the process harmonic index κ. The quantity κ is determined by the formula

$$\kappa = \frac{\ddot{y}_0^{(max)} \cdot y_0^{(max)}}{\left(\dot{y}_0^{(max)}\right)^2} \quad (6)$$

According to the American NPP calculation standards [21], the value of κ is assumed to be 5. In studies [22], it is noted that this parameter decreases with increasing the prevailing earthquake input period and it varies from 3 to 7. For harmonic action κ = 1. The larger κ, the more the process differs from the harmonic one. Large values of κ for the model do not allow one to concentrate the input energy at one frequency.

Kinematic characteristics of the impact are very important for elastic calculations under the loads caused by design earthquake (DE).

Input spectral characteristics, i.e. input spectral composition, are not considered in the framework of the proposed approach. Excitation frequencies ωi are set to be hazardous for the structure. This approach allows one of the frequencies ωi to be set equal to the prevailing frequency of the excitation predicted by seismologists, but in this case calculations will not be conservative.

Energy characteristics of the excitation determine the structure behavior under the impact of the MDE. Among these characteristics are

1) Arias intensity

$$I_A = \frac{\pi}{2g}\int_0^T \ddot{y}_0^2 dt \quad (7)$$

2) Absolute cumulative velocity CAV

$$CAV = \int_0^T \left|\ddot{y}_0\right| dt \quad (8)$$

3) Seismic energy density SED

$$SED = \int_0^T \dot{y}_0^2 dt \quad (9)$$

In the given investigation five parameters of the seismic input PGA, κ, I_A, CAV and SED are taken into account.

Results and Discussion

To estimate the values of input parameters corresponding to real accelerograms, more than 100 accelerogram records included in the combined database of Russian and Chinese accelerograms have been analyzed. During the research the dependence of the input parameters on the prevailing input frequency was analyzed.

The dependence $\ddot{y}_0(t)$ had been considered earlier in papers [18, 20], and the decrease of the PGA value was found with the growth of the predominant period T_{eq} increasing.

The dependence $\kappa(T_{eq})$ is shown in Figure 2, where the points indicate the data of the records of past earthquakes available for the authors. In this case for high-frequency inputs with the predominant period T_{eq}≈0.05…0.015 s, the value of κ can be about 10–15, and for long-period inputs the value of κ decreases down to 2–3. For some impacts, e.g., for the Bucharest earthquake κ≈1.5. It should be noted that a decrease in κ makes the input dangerous. Therefore, in order to generate hazardous input on the structure, it seems justified to set the value of κ according to the proposed schedule $\kappa(T_{eq})$ or somewhat lower, taking as a design value the follows

$$\kappa_{calc} = \kappa - \alpha \cdot \sigma, \quad (10)$$

where σ is the standard deviation of κ from the mean value,

α is the reliability index of the assumed design value.

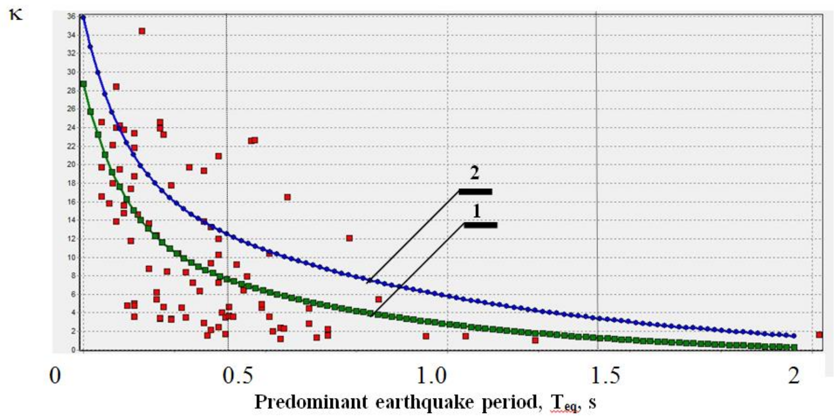

Figure2. Dependence $\kappa(T_{eq})$ obtained on the basis of the available records of real accelerograms.

1 – average value; 2 – $\kappa(T_{eq})$ - σ

Energy indicators are sufficiently stable characteristics of seismic input. Figure 3 shows the dependence I_A(Teq). The records of past earthquakes available to authors are denoted in the picture by points, and the mathematical expectation of the value and the sum of the mathematical expectation and standard deviation are denoted by lines. According to our data, the I_A value decreases slightly from 5 to 4 m/s with the growth of T_{eq}. In this case, the quantity $I_A + \sigma_I$≈8. It can be noted, that according to the data of [23], there is also a slight decrease in the value of I_A with an increase in the prevailing period. In the range of T_{eq} from 0.1 to 0.5 s I_A ≈ 2.53 m/s, and for Teq> 0.5 s I_A ≈2. If we take into account that the intensity of earthquakes considered in [23] is within the range of 8–9 degrees on the MSK scale, and the earthquakes considered in this paper have intensity of 9 or more degree, then the results obtained are quite compatible. Analogous dependencies can be obtained for other energy characteristics, in particular, for the CAV value. Between the quantities under consideration there is clear-cut correlation dependence, shown in Figure 4. This makes it possible to use any of the parameters under consideration when generating the design input. In Recommendations [11], the intensity according to Arias is given as the energy characteristic, and in the paper of American experts [23] the preference is given to the value of CAV.

$$Error = \sum_{i=1}^{5} p_i \cdot Er_i$$

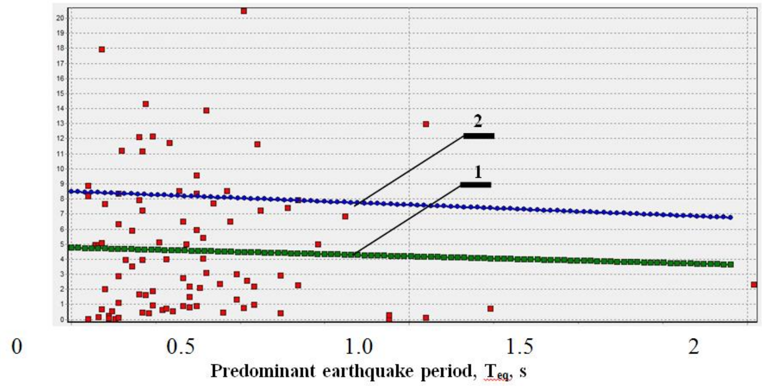

Figure 3. Dependence I_A(Teq). 1 – average value; 2 – $I_A(T_{eq})$ +σ_I

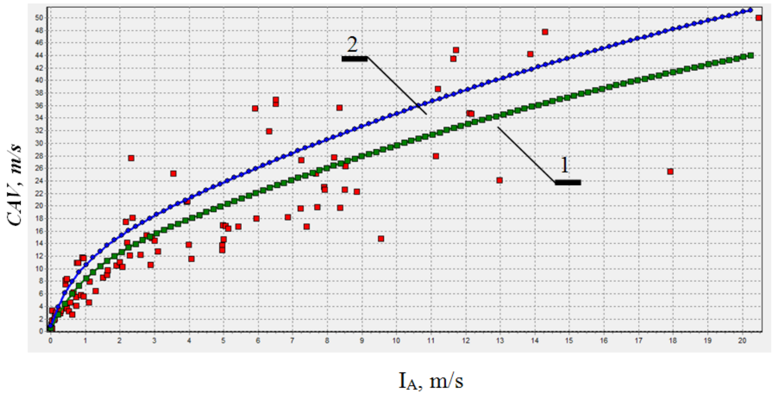

Figure 4. Dependence of CAV (I_A). 1 – average value of CAV (IA); 2 – CAV(I_A)+σ_{CAV}

The data of real accelerograms are denoted by dots

In paper [24], it is proposed to use the SED as the basic energy parameter. This value, according to the data available to the authors, does not correlate with the two energy characteristics considered before. It is sufficiently stable and in the first approximation it can be assumed to be equal to 1.5.

The obtained empirical dependencies are used to specify 12 indeterminate parameters of formula (1). To do this, some weight is assigned to each of the five parameters (PGA, κ, I_A, CAV, SED), and an error between the given empirical values and the analogous values obtained from formulas (6–9) is calculated at each grid point of the variable parameters.

By assigning different weight coefficients we get a set of dangerous inputs, with a close spectral composition. When choosing the coefficients, it seems possible to start with the following considerations.

Calculations for the impact of the DE are force ones, and the result of calculation, strains and stresses in the elements of the construction are proportional to the value of PGA. Therefore, when generating a DE, one should assign a large weighting factor for PGA.

Calculations for the impact of the MDE are energy ones. The strength condition of the elements is not met, but it is necessary to exclude progressive collapse and low cycle fatigue of the main load-bearing elements. To do this, it is necessary to get a limit to work of plastic deformation forces [25–28]. In this case energy characteristics are most important for the model input.

It is also important to limit the concentration of all seismic energy at one frequency both for the DE and for the MDE. Therefore, the weighting factor of κ must be taken into account for both inputs.

As an example, Figure 5 shows two generated accelerograms for calculating a building with suspended members [29], a seismically isolated structure with periods of natural oscillations T1 = 4.243 s, T2 = 3.145 s, T3 = 0.054 s. Table 1 shows the characteristics of these accelerograms. When generating the first accelerogram, three weight coefficients are assumed to be nonzero: p_{PGA} = 0.6, $p_κ$ = 0.3, p_{IA} = 0.1, and for the second accelerogram p_{PGA} = 0.1; $p_κ$ = 0.3; p_{IA} = 0.6. The generated accelerograms are quite similar, although they have some differences, for example, in residual displacements. This confirms the validity of the hypothesis expressed in [1] which supposes that taking into account the dependence of the peak acceleration on the prevailing acceleration period ensures that the parameters of the model and real excitations coincide.

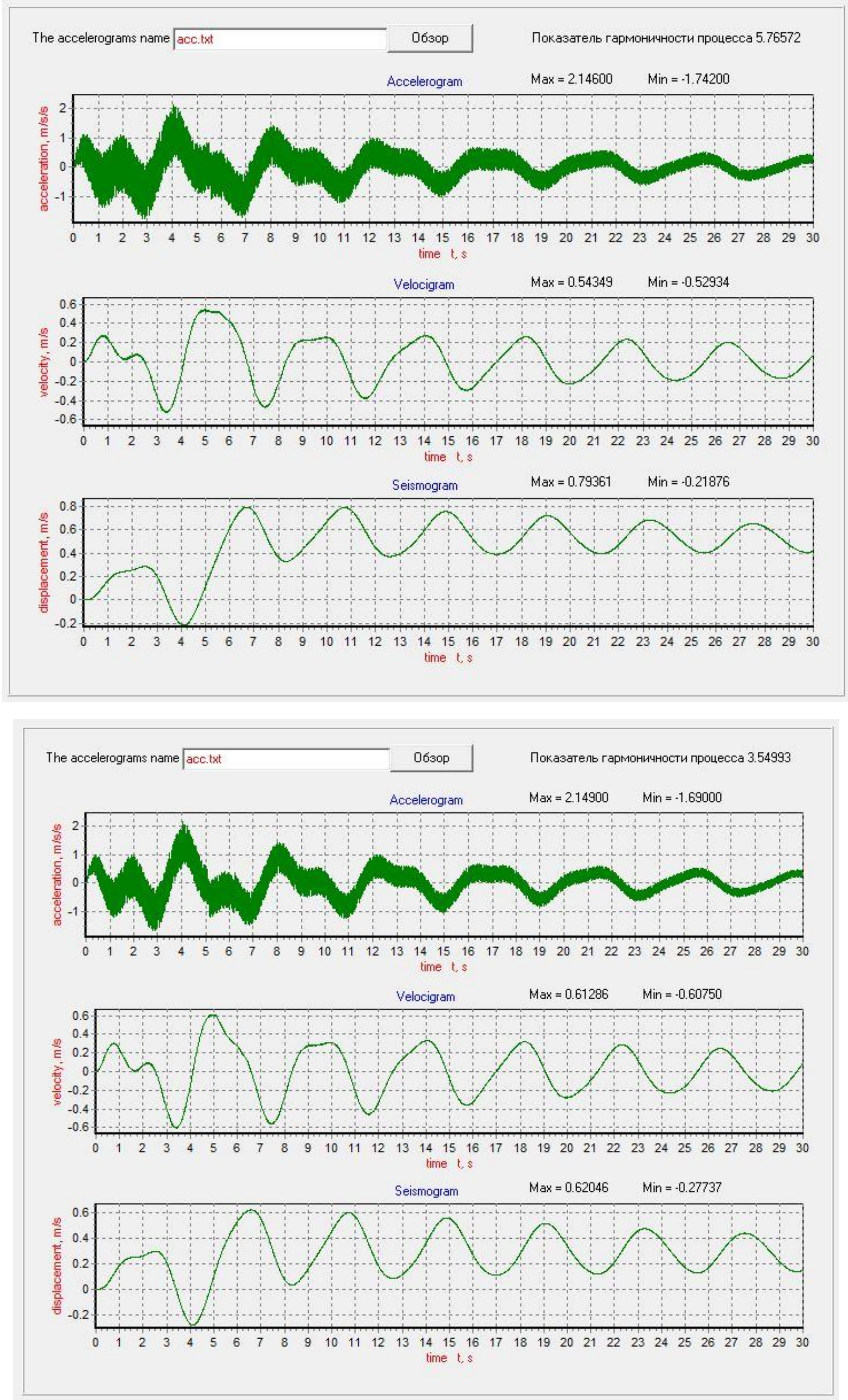

Fig.5. Oscillograms of artificial input for pPGA = 0.1 (on top) and pPGA = 0.6 (on bottom)

Table 1. Artificial input characteristics

Input charcteristics	**The type of input**	
	$p_{PGA} = 0.6$	$p_{PGA} = 0.1$
PGA	2.146	2.149
κ	3.55	5.76
I_A, m/s	1.368	1.343
CAV, m/s	12.02	12.23
SED, m^2/s	1.55	2.0

Conclusions

As the result of the investigations a new input model with a spectral composition that is dangerous for the structure under consideration, and with kinematic and energy characteristics corresponding to real seismic excitations has been generated. This new input model can be considered as a certain compromise between the model for the building site and the model for the structure.

Acknowledgements

The authors are grateful to the Russian Foundation for Fundamental Research. This paper has been prepared within the framework of the RFFR grant No. 16-58-53095 "Development of the theory of limit states for ensuring seismic stability of railway bridges under construction and operation".

The authors thank S.R.Grebenschikova for help in preparing the English text of the paper.

References

1. Uzdin A.M. Zadaniye seysmicheskogo vozdeystviya. Vzglyad inzhenera-stroitelya [The task of seismic action. The view of a civil engineer]. *Earthquake engineering. Constructions safety.* 2005. No. 1. Pp. 27–31. (rus)
2. Uzdin A.M. Chto skryvayetsya za lineyno-spektralnoy teoriyey seysmostoykosti [What lies behind the linear-spectral theory of seismic resistance]. *Earthquake engineering. Constructions safety.* 2009. No. 2. Pp. 18–23. (rus)
3. Aptikayev F.F. Prognoz parametrov seysmicheskikh kolebaniy, postroyeniye lokalnogo spektra i sinteticheskoy akselerogrammy [Forecast of seismic oscillation parameters, construction of local spectrum and synthetic accelerogram]. *Proceedings “Seysmostoykoye stroitelstvo v epokhu mogushchestva i schastya”.* Ashkhabad, Ylym, 2013. Pp. 285–304. (rus)
4. Vakhrina G.N., Smirnov V.I. Razvitiye modeley raschetnykh akselerogramm seysmicheskikh vozdeystviy [Development of models of calculated accelerograms of seismic effects]. *Earthquake engineering. Constructions safety.* 2013. No. 1. Pp. 29–39. (rus)
5. Bani-Hani K.A., Malkawi A.I. A multi-step approach to generate response-spectrum-compatible artificial earthquake accelerograms. *Soil Dynamics and Earthquake Engineering.* 2017. Vol. 97. Pp. 117–132.
6. Vrochidou E., Alvanitopoulos P., Andreadis I., Elenas A., Mallousi K. HHT-Based artificial seismic accelerograms generation. *IFIP International Conference on Artificial Intelligence Applications and Innovations. AIAI 2014: Artificial Intelligence Applications and Innovations.* 2014. Pp. 476–486.
7. Li Zh., Kotronis P., Wu H. Simplified approaches for Arias Intensity correction of synthetic accelerograms. *Bulletin of Earthquake Engineering.* March 2017. Pp. 1–21.
8. Zentner I., Allain F., Humbert N., Gaudron M. Generation of spectrum compatible ground motion and its use in regulatory and performance-based seismic analysis. *Proceedings of the 9th International Conference on Structural Dynamics. EURODYN 2014.* Porto, Portugal, 2014. Pp. 381–384.
9. Kuznetsova I.O., Uzdin A.M., Zhgutova T.V., Shulman S.A. Seismic protection of railway bridges in Sochi. Proceedings of workshop “Bridges seismic isolation and large-scale modeling”. Saint-Petersburg, 2010. Pp. 39–41.
10. Guzeyev R.V. Algoritm generatsii sinteticheskikh akselerogramm iz usloviya maksimalnogo sovpadeniya spektra otklika i normativnoy krivoy dinamichnosti [Algorithm for generating synthetic accelerograms from the condition of maximum coincidence of the response spectrum and the normative dynamic curve]. *Earthquake engineering. Constructions safety.* 2010. (rus)
11. *Rekomendatsii po zadaniyu seysmicheskikh vozdeystviy dlya rascheta zdaniy raznoy stepeni otvetstvennosti* [Recommendations for assigning seismic impacts for the

Литература

1. Уздин А.М. Задание сейсмического воздействия. Взгляд инженера-строителя // Сейсмостойкое строительство. Безопасность сооружений. 2005. № 1. С. 27–31.
2. Уздин А.М. Что скрывается за линейно-спектральной теорией сейсмостойкости // Сейсмостойкое строительство. Безопасность сооружений. 2009. № 2. С. 18–23.
3. Аптикаев Ф.Ф. Прогноз параметров сейсмических колебаний, построение локального спектра и синтетической акселерограммы // Сб. Сейсмостойкое строительство в эпоху могущества и счастья. Ашхабад, Ылым, 2013. С. 285–304.
4. Вахрина Г.Н., Смирнов В.И. Развитие моделей расчетных акселерограмм сейсмических воздействий // Сейсмостойкое строительство. Безопасность сооружений. 2013. № 1. С. 29–39.
5. Bani-Hani K.A., Malkawi A.I. A multi-step approach to generate response-spectrum-compatible artificial earthquake accelerograms // Soil Dynamics and Earthquake Engineering. 2017. Vol. 97. Pp. 117–132.
6. Vrochidou E., Alvanitopoulos P., Andreadis I., Elenas A., Mallousi K. HHT-Based artificial seismic accelerograms generation // IFIP International Conference on Artificial Intelligence Applications and Innovations. AIAI 2014: Artificial Intelligence Applications and Innovations. 2014. Pp. 476–486.
7. Li Zh., Kotronis P., Wu H. Simplified approaches for Arias Intensity correction of synthetic accelerograms // Bulletin of Earthquake Engineering. 2017. March. Pp. 1–21.
8. Zentner I., Allain F., Humbert N., Gaudron M. Generation of spectrum compatible ground motion and its use in regulatory and performance-based seismic analysis // Proceedings of the 9th International Conference on Structural Dynamics. EURODYN 2014. Porto, Portugal, 2014. Pp. 381–384.
9. Kuznetsova I.O., Uzdin A.M., Zhgutova T.V., Shulman S.A. Seismic protection of railway bridges in Sochi // Proceedings of workshop “Bridges seismic isolation and large-scale modeling”. Saint-Petersburg, 2010. Pp. 39–41.
10. Гузеев Р.В. Алгоритм генерации синтетических акселерограмм из условия максимального совпадения спектра отклика и нормативной кривой динамичности // Сейсмостойкое строительство. Безопасность сооружений. 2010. С. 17–19.
11. Рекомендации по заданию сейсмических воздействий для расчета зданий разной степени ответственности. С.-Петербург–Петропавловск-Камчатский. КамЦентр. 1996. 12 с.
12. Никонова Н.В. Особенности задания воздействия и расчета нелинейных систем сейсмоизоляции // Известия Петербургского университета путей сообщения. 2016. № 3. С. 430–438.

calculation of buildings of different degrees of responsibility] S.-Peterburg–Petropavlovsk-Kamchatskiy. KamTsentr. 1996. 12 p. (rus)

12. Nikonova N.V. Osobennosti zadaniya vozdeystviya i rascheta nelineynykh sistem seysmoizolyatsii [Features of the task of impact and calculation of nonlinear seismic isolation systems]. *Izvestiya Peterburgskogo universiteta putey soobshcheniya.* 2016. No. 3. Pp. 430–438 (rus)
13. SP 14.13330.2011 Stroitelstvo v seysmicheskikh rayonakh [Russian Set of Rules SP 14.13330.2011 Construction in seismic regions]. (rus)
14. *Seysmicheskaya sotryasayemost territorii SSSR* [Seismic shaking of the territory of the USSR]. Ed. Yu.V.Riznichenko. Moscow: Nauka, 1979. 192 p. (rus)
15. Dmitrovskaya L.N., Uzdin A.M. Ob odnoy forme predstavleniya seysmicheskogo vozdeystviya dlya otsenki korrelyatsii kolebaniy tochek dnevnoy poverkhnosti pri raschete mnogoopornykh konstruktsiy [On one form of representation of seismic action for estimating the correlation of fluctuations of the points of the day surface in the calculation of multi-support structures]. *Earthquake engineering. Constructions safety.* 2006. No. 2. Pp. 22–25. (rus)
16. Faccioli E., Paolicci R., Rey Ju. Displacement spectra for long periods. *Earthquake Spectra.* Vol. 20. No. 2. Pp. 347–376.
17. Uzdin A.M., Dmitrovskaya L.N., Sakharov O.A. Setting the level of design acceleration on the basis of the energy theory of earthquake engineering. *Fourteen European Conference on Earthquake Engineering.* Macedonia, Ochrid, 2010. CD-paper No. 189. Abstract Book. R. 98.
18. Dolgaya A.A. Modelirovaniye seysmicheskogo vozdeystviya korotkim vremennym protsessom [Simulation of seismic action by a short time process]. *Ekspress-informatsiya VNIINTPI. Ser. "Seysmostoykoye stroitelstvo"*. 1994. No. 5-6. Pp. 56–63. (rus)
19. Dolgaya A.A., Indeykin A.V. Statisticheskiy analiz intensivnosti po Ariasu i skorosti dlya realnykh zemletryaseniy [Statistical analysis of Arias intensity and velocity for real earthquakes]. *Seysmostoykoye stroitelstvo.* 2002. No. 2. Pp. 32–33. (rus)
20. Bogdanova A.M., Nesterova O.P., Nikonova N.V., Tkachenko A.S., Uzdin A.M., Ravkhmanova M., Azayev T.M., Zaynulabidova Kh.R. Chislovyye kharakteristiki seysmicheskikh vozdeystviy [Numerical characteristics of seismic actions]. *Nauka i mir.* 2017. Vol. 1. No. 3(43). Pp. 49–55. (rus)
21. Birbrayer A.N. *Raschet konstruktsiy na seysmostoykost* [Calculation of structures for seismic resistance]. Saint-Petersburg: Nauka, 1998. 254 p. (rus)
22. Bogdanova G.A., Dolgaya A.A., Ivanova J.V, Sakharov O.A., Uzdin A.M. The model of seismic impact as a short temporary process for calculating of the seismoisolated systems. *12th World Conference on Earthquake Engineering.* New Zealand, 2000. Paper No. 1358.
23. Campbell K.W., Bozorgnia Y. Cumulative absolute velocity (cav) and seismic intencity based on the peer-nga database. *Earthquake Spectra.* 2012. Vol. 28. No. 2. Pp. 457–485.
24. Rutman Yu.L., Shiwua J. Otsenki seysmicheskoy energii, postupivshey v uprugo-plasticheskuyu sistemu s odnoy stepenyu svobody [Estimates of seismic energy received in an elastic-plastic system with one degree of freedom]. *Vestnik grazhdanskikh inzhenerov SPbGASU*. 2015. No. 2(49). Pp. 64–74. (rus)
25. Goldenblat I.I., Nikolayenko N.A., Polyakov S.V., Ulyanov S.V. *Modeli seysmostoykosti sooruzheniy* [Models of seismic stability of structures]. Moscow: Stroyizdat,1979. 251 p. (rus)

13. СП 14.13330.2011 Строительство в сейсмических районах. Актуализированная редакция СНиП II-7-81*.
14. Сейсмическая сотрясаемость территории СССР. Под ред. Ю.В. Ризниченко. М.: Наука, 1979. 192 с.
15. Дмитровская Л.Н., Уздин А.М. Об одной форме представления сейсмического воздействия для оценки корреляции колебаний точек дневной поверхности при расчете многоопорных конструкций // Сейсмостойкое строительство. Безопасность сооружений. 2006. № 2. С. 22–25.
16. Faccioli E., Paolicci R., Rey Ju. Displacement spectra for long periods // Earthquake Spectra. Vol. 20. № 2. Pp. 347–376.
17. Uzdin A.M., Dmitrovskaya L.N., Sakharov O.A. Setting the level of design acceleration on the basis of the energy theory of earthquake engineering // Fourteen European Conference on Earthquake Engineering. Macedonia.Ochrid. 2010. CD-paper №189. Abstract Book. P. 98.
18. Долгая А.А. Моделирование сейсмического воздействия коротким временным процессом // Экспресс-информация ВНИИНТПИ. Сер. "Сейсмостойкое строительство". 1994. № 5-6. С. 56–63.
19. Долгая А.А., Индейкин А.В. Статистический анализ интенсивности по Ариасу и скорости для реальных землетрясений // Сейсмостойкое строительство. № 2. 2002. С. 32–33.
20. Богданова А.М., Нестерова О.П., Никонова Н.В., Ткаченко А.С., Уздин А.М., Равхманова М., Азаев Т.М., Зайнулабидова Х.Р. Числовые характеристики сейсмических воздействий // Наука и мир. № 3(43). 2017. Т. 1. С. 49–55.
21. Бирбраер А.Н. Расчет конструкций на сейсмостойкость. СПб.: Наука. 1998. 254 с.
22. Bogdanova G.A., Dolgaya A.A., Ivanova J.V, Sakharov O.A., Uzdin A.M. The model of seismic impact as a short temporary process for calculating of the seismoisolated systems // 12th World Conference on Earthquake Engineering. New Zealand, 2000. Paper No. 1358.
23. Campbell K.W., Bozorgnia Y. Cumulative Absolute velocity (cav) and seismic intencity based on the PEER-NGA database // Earthquake Spectra. 2012. Vol. 28. № 2. Pp. 457–485.
24. Рутман Ю.Л., Шивуа А.Дж. Оценки сейсмической энергии, поступившей в упруго-пластическую систему с одной степенью свободы // Вестник гражданских инженеров СПбГАСУ. 2015. № 2(49). С. 64–74.
25. Гольденблат И.И., Николаенко Н.А., Поляков С.В., Ульянов С.В. Модели сейсмостойкости сооружений. М.: Стройиздат,1979.251 с.
26. Москвитин В.В. Циклические нагружения элементов конструкций. М.: Наука, 1981. 344 с.
27. Erberik M.A., Sucuoglu H. Energy-based low-cycle fatigue characteristics of degrading structures // Proc. of 12-th European Conference on Earthquake Engineering. Paper Reference 118.
28. Shiwua J., Rutman Y. Assessment of seismic input energy by means of new definition and the application to earthquake resistant design // Architecture and Engineering. 2016. Vol. 1. № 4. Pp. 26–35.
29. Белаш Т.А., Рыбаков П.Л. Здания с подвесными конструкциями в сейсмических районах // Инженерно-строительный журнал. 2016. № 5(65). С. 17–26.

Иванова Т.В., Гуань Ю., Нестерова О.П., Прокопович С.В., Смирнова Л.Н., Уздин А.М., Ивашинцов Д.А. Моделирование расчетного сейсмического воздействия в условиях ограниченной сейсмологической информации // Инженерно-строительный журнал. 2017. № 7(75). С. 129–138.

26. Moskvitin V.V. *Tsiklicheskiye nagruzheniya elementov konstruktsiy* [Cyclic loading of structural elements]. Moscow: Nauka, 1981. 344 p. (rus)
27. Erberik M.A., Sucuoglu H. Energy-based low-cycle fatigue characteristics of degrading structures. *Proc. of 12-th European Conference on Earthquake Engineering.* Paper Reference 118.
28. Shiwua J., Rutman Y. Assessment of seismic input energy by means of new definition and the application to earthquake resistant design. *Architecture and Engineering.* 2016. Vol. 1. No. 4. Pp. 26–35.
29. Belash T.A., Rybakov P.L. Buildings with suspended structures in seismic areas. *Magazine of Civil Engineering*. 2016. No.5. Pp. 17–26.

Tatiana Ivanova,
+7(812)493-93-63; IvanovaTV@vniig.ru

Jhy Guan,
+7(921)788-33-64; 329953890@qq.com

Olga Nesterova,
+7(960)280-59-75; Neona975@yandex.ru

Sergey Prokopovich,
+7(981)103-26-72; spr94@outlook.com

Lybov Smirnova,
+7(985)472-29-77; lyubovsmirnova80@gmail.com

Aleksandr Uzdin,
+7(921)788-33-64; uzdin@mail.ru

Dmitry Ivashintzov,
+7(921)3680757; ivashintsov@gmail.com

Татьяна Викторовна Иванова,
+7(812)493-93-63; эл. почта: IvanovaTV@vniig.ru

Юхай Гуань,
+7(921)788-33-64;
эл. почта: 329953890@qq.com

Ольга Павловна Нестерова,
+7(960)280-59-75;
эл. почта: Neona975@yandex.ru

Сергей Владимирович Прокопович,
+7(981)103-26-72; эл. почта: spr94@outlook.com

Любовь Николаевна Смирнова,
+7(985)472-29-77;
эл. почта: lyubovsmirnova80@gmail.com

Александр Моисеевич Уздин,
+7(921)788-33-64; эл. почта: uzdin@mail.ru

Дмитрий Александрович Ивашинцов,
+7(921)368-07-57;
эл. почта: ivashintsov@gmail.com

Ivanova T.V., Guan J., Nesterova O.P., Prokopovich S.V., Smirnova L.N., Uzdin A.M., Ivashintzov D.A. Modeling the design seismic input in conditions of limiting seismological information. *Magazine of Civil Engineering*. 2017. No. 7. Pp. 129–138. doi: 10.18720/MCE.75.13.