**Оптимизация конструктивных параметров пластических демпферов в системах сейсмоизоляции**

**Optimization of plastic dampers design parameters in seismic isolation systems**

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**Аннотация.** Эффективность применения систем сейсмоизоляции (ССИ) в значительной мере зависит от правильного выбора параметров демпфирования. В докладе рассматривается задача поиска оптимальных параметров пластических демпферов (ПД) в ССИ. Основное внимание уделено методологии варьирования и выбора конструктивных параметров ПД с целью реализации оптимального коэффициента демпфирования , используемого в линеаризованной динамической модели сейсмоизоляции.

Получен ряд аналитических зависимостей, позволяющих найти силовую характеристику ПД различной конфигурации (прямолинейных и криволинейных). Рассмотрены различные варианты нагружения ПД (в т.ч. пространственное нагружение).

Также рассмотрены численные методы установления силовых характеристик (с помощью ПК «ANSYS» и метода псевдожесткостей). Приведено сравнение силовой характеристики, вычисленной с помощью ПК «ANSYS», криволинейного ПД с экспериментом.

**Ключевые слова**:системы сейсмоизоляции,пластический демпфер,поископтимальных параметров демпфирования, метод псевдожесткостей

**Annotation** The effectiveness of the use of seismic isolation systems (SIS) largely depends on the correct choice of damping parameters. The report deals with the task of finding the optimal parameters of plastic dampers (PD) in the SIS. The main attention is paid to the methodology of variation and selection of design parameters of PD in order to implement the optimal damping coefficient  used in the linearized dynamic model of seismic isolation.

A number of analytical dependencies were obtained, allowing to find the power characteristic of PD of various configurations, both straight and curvilinear. The various options for loading PD including spatial loading are considered.

Numerical methods for determining power characteristics (using the «ANSYS» software package and the pseudo-hardness method) wereconsidered also. A comparison of the curvilinear PD power characteristics, calculated by using «ANSYS», with the experiment was carried out.

**Keywords**: seismic isolation system, plastic damper, search of optimum damping parameters,pseudorigidity method

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1. **Introduction**

One of the most effective criteria for optimizing a seismically isolated system (SIS) is the criterion for minimizing the absolute accelerations of the protected object (PO) [1, 2, 3]. This criterion can significantly reduce construction costs of building of seismically isolated objects. The optimization of damping parameters plays a significant role for this criterion.Methods of implementation of the optimal parameters of the dynamic model of an SIS by choosing the design characteristics of plastic dampers (PD) are being researched in this report.

**2. Formulation of the problem**

The mathematical model of the SIS is non-linear and contains at least 3 parameters characterizing the power characteristic of plastic dampers.The linearization of the model and the use of the Voigt-Bocca hypothesis allows one to characterize the damping with just one parameter — a dimensionless damping coefficient [4].Varying this coefficient you can set its optimal value.This raises the problem of the implementation of this coefficient in specific designs of PD.To do this, you need to be able to set the power characteristic of the PD or its main parameters using relatively simple means.

1. **Analytical dependencies and software for obtaining power characteristics of PD or determining the main parameters of these characteristics**

**A)** If the PD is a straight rod of rectangular cross section, then the power characteristic isdescribed by the following parametric dependencies [5, 6]:

$p\left(t\right)=\frac{\left(3t^{2}-1\right)+a(2t+1)(t-1)^{2}}{6t^{2}}$ (1)

$w\left(t\right)=\frac{2t\left(4a^{2}t^{6}+9a\left(1-a\right)t^{5}+(20-21a+6alnt\right)\left(1-a\right)t^{3}-\left(1-a\right)^{2}(18t^{2}-2))}{3(4a^{2}t^{6}+12a\left(1-a\right)t^{5}+(1-a)^{2}\left(9t^{4}-6t^{2}+1\right)-4a\left(1-a\right)t^{3})}$,

$p≡\frac{2Pl}{σ\_{T}b\_{o}h^{2}}$, $w≡\frac{Wh}{ε\_{T}l^{2}}$. (2)

In these formulas *p*(*t*) , *w*(*t*) – values associated with the physically meaningful parameters (force and displacement) by relations (2); *a*  *Eпл* *E* ; *t* – dimensionless parameterthat forms the power characteristic. The remaining obvious symbols describe the size of the rod, its cross-section and the characteristics of the material of the rod. For rods of circular cross section there are similar dependencies [6].

1. In [6] there are analytical dependencies for obtaining the force characteristics of flat curvilinear rods, if the force acting on PD lies in the plane of the rod. However, such dependencies cannot be obtained if the load on PD is perpendicular to the plane of the rod.In this case one can consider as the rigid-rod structure and obtain the formula for calculating its yield surface (curve describing actuation PD). These formulas are:

$\frac{P\_{BX}}{P\_{TX}}=\frac{1}{\sqrt{1+βtg^{2}θ}}$, $\frac{P\_{BZ}}{P\_{TZ}}=\frac{1}{\sqrt{1+βtg^{2}θ}}$, (3)

In the above formulas *PBZ* , *PBX* – the components of the force applied to the PD (axis Z perpendicular to the plane of the rod); $\frac{M\_{TX}^{2}}{M\_{TZ}^{2}}=α$, $\frac{M\_{TZ}^{6}}{M\_{TX}^{6}}=β$, *MTZ*, *MTX* – limiting moments in bending around the axes *X*, *Z*; *PTZ* , *PTX* – limiting forces along the Z, X axes.

An effective method for determining PD triggering forces is the use of the pseudo-rigidness method [7]. In [7], a PD consisting of several curved rods was considered and its yield surface was found (Table 1).

**Table 1. Surface yield a three-dimensional plastic damper**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ° | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| *PY* / *PTY* | 1 | 0.881 | 0.731 | 0.587 | 0.462 | 0.344 | 0.25 | 0.156 | 0.081 | 0 |
| *PX / PTY* | 0 | 0.156 | 0.262 | 0.337 | 0.387 | 0.412 | 0.431 | 0.437 | 0.444 | 0.45 |

In the table it is accepted: *PY*, *PX* – components of a maximum load; ° – the angle between the Y axis and the load applied to the damper lying in the XY plane; *PTY* – the value of the maximum load at  0.

1. **Using the finite element method (FEM) and software package «ANSYS»**

Numerical analysis showed that the use of elastoplastic models of FEM yields results that

differ from the results obtained by the above methods by no more than 5–10% [6]. It should be borne in mind that the formulas of paragraph A give an exact solution in the framework of the theory of Kirchhoff-Clebsch rods. However, calculations based on FEM using an «ANSYS» SP require the use of high-dimensional models and, accordingly, a large time resource.This is usually not possible in design practice.

1. **The experiment**

To establish the adequacy of methods for calculating PD, an experiment was carried out and a finite element calculation was performed using the «ANSYS» computer package [8]. A comparison of the experimental and calculated power characteristics showed that the force characteristics of the PD give results that differ from the experiment by no more than 5%. The type of deformation of PD in the calculation and experiment coincide.

1. **Conclusion**

The article considers the problem of optimizing the design parameters of plastic dampers in the SIS.The target function is the dimensionless damping coefficient, which minimizes the absolute accelerations of the PO.Various methods for the selection of design parameters of PD for the implementation of the optimal damping coefficient in the linearized dynamic model of the SIS are proposed.

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