BUILDING CONSTRUCTIONS, BUILDINGS AND ENGINEERING STRUCTURES

СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ

Check for updates

Original Empirical Research

UDC 624.014
https://doi.org/10.23947/2949-1835-2025-4-3-18-24

EDN: LFBASG

Energy-Absorbing Gusset of Steel Frame Bonds

Maria P. Kotenko[1] ✉, **Sergey V. Skachkov**[2]
[1] Rostov State Transport University, Rostov-on-Don, Russian Federation
[2] Don State Technical University, Rostov-on-Don, Russian Federation
✉ maria.kotencko2016@yandex.ru

Abstract

Introduction. This study looks at the urgent problem of ensuring the seismic resistance of buildings and structures in areas with increased seismic activity. The aim of the study is a comprehensive analysis of existing methods of protection against seismic impacts and the development of innovative design solutions in order to increase the stability of buildings. The study is relevant due to the growing need to protect the population and infrastructure in seismically active regions around the globe.

Materials and Methods. Two major approaches to increasing seismic resistance were considered: the traditional method of increasing structural cross-sections and a special method of reducing load by means of changing the dynamic scheme of the structure. Special attention is paid to the development and analysis of the operation of the fastening unit of the frame using a curved thin-walled plate. Modern methods of mathematical modeling and computer analysis were employed.

Research Results. Architectural, planning and constructive solutions for increasing the earthquake resistance of buildings were analyzed. The principles of designing earthquake-resistant buildings to minimize earthquake damage were formulated. The plastic properties of steel as an effective method of absorbing seismic energy were studied. Energy-absorbing devices are classified into five main types: rod-type, annular, tubular, beam-type and shear-type. The design features of energy absorbers, their advantages and disadvantages were thoroughly investigated.

Discussion and Conclusion. A finite element analysis of the stress-strain state of the fastening unit was conducted by means of the Stark ES software package. The results of the analysis enabled us to evaluate the efficiency of the suggested constructive solution. The practical importance of the study lies in the possibility of applying the developed solutions in the design and construction of earthquake-resistant buildings in areas of increased seismic activity. The suggested methods and designs make it possible to increase the stability of buildings, reduce metal consumption, and easy to replace elements if needed. The developed solutions can be scaled for use in different types of building structures and climatic conditions.

Keywords: seismic resistance, energy absorbers, seismic impact, design solutions, building design, active seismic protection, seismic isolation systems, damping, vibration absorbers, seismic resistance of buildings, design solutions

For citation. Kotenko MP, Skachkov SV Energy-Absorbing Gusset of Steel Frame Bonds. *Modern Trends in Construction, Urban and Territorial Planning.* 2025;4(3):18–24. https://doi.org/10.23947/2949-1835-2025-4-3-18-24

Оригинальное эмпирическое исследование

Энергопоглощающие фасонки связей стального каркаса

М.П. Котенко[1] ✉, **С.В. Скачков**[2]
[1] Ростовский государственный университет путей сообщения, г. Ростов-на-Дону, Российская Федерация
[2] Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация
✉ maria.kotencko2016@yandex.ru

Аннотация

Введение. Настоящая работа посвящена актуальной проблеме обеспечения сейсмостойкости зданий и сооружений в зонах с повышенной сейсмической активностью. Целью исследования является комплексный анализ существующих методов защиты от сейсмических воздействий и разработка инновационных конструктивных решений

для повышения устойчивости зданий. Актуальность исследования обусловлена растущей необходимостью защиты населения и инфраструктуры в сейсмически активных регионах мира.
Материалы и методы. В ходе исследования рассмотрены два основных подхода к повышению сейсмостойкости: традиционный метод увеличения сечений конструкций и специальный метод снижения нагрузки через изменение динамической схемы работы сооружения. Особое внимание уделено разработке и анализу работы узла крепления связи каркаса с использованием фасонки из гнутой тонкостенной пластины. Для проведения исследования применялись современные методы математического моделирования и компьютерного анализа.
Результаты исследования. Выполнен анализ архитектурно-планировочных и конструктивных решений, направленных на повышение сейсмостойкости зданий. Сформулированы принципы проектирования сейсмостойких зданий, обеспечивающих минимизацию ущерба от землетрясений. Проведено исследование пластических свойств стали как эффективного способа поглощения сейсмической энергии. Представлена классификация энергопоглощающих устройств по пяти основным типам: стержневые, кольцевые, трубчатые, балочного типа и работающие на сдвиг. Детально изучены конструктивные особенности энергопоглотителей, их преимущества и недостатки.
Обсуждение и заключение. Проведен конечно-элементный анализ напряженно-деформированного состояния узла крепления с использованием программного комплекса Stark ES. Результаты анализа позволили оценить эффективность предложенного конструктивного решения. Практическая значимость исследования заключается в возможности применения разработанных решений при проектировании и строительстве сейсмостойких зданий в зонах повышенной сейсмической активности. Предложенные методы и конструкции позволяют повысить устойчивость зданий, снизить металлоемкость и обеспечить простоту замены элементов при необходимости. Разработанные решения могут быть масштабированы для применения в различных типах строительных конструкций и климатических условиях.

Ключевые слова: сейсмостойкость, энергопоглотители, сейсмическое воздействие, конструктивные решения, проектирование зданий, активная сейсмозащита, системы сейсмоизоляции, демпфирование, гасители колебаний, конструктивные решения

Для цитирования. Котенко М.П., Скачков С.В. Энергопоглощающие фасонки связей стального каркаса. *Современные тенденции в строительстве, градостроительстве и планировке территорий*. 2025;4(3):18–24. https://doi.org/10.23947/2949-1835-2025-4-3-18-24

Introduction. Earthquakes are among the most destructive natural phenomena causing massive damage to buildings and structures, particularly in areas with increased seismic activity. Ensuring the earthquake resistance of buildings is a key task facing modern architecture and engineering in order to protect human life and health, as well as to preserve material assets.

With earthquakes occurring frequently, it is critical to develop and implement innovative design solutions to minimize damage and ensure the safety of buildings. One of the urgent issues is designing constructive methods in order to increase the overall earthquake resistance of buildings and their individual elements.

The main aim of the research is a comprehensive study of existing methods of protecting buildings from seismic effects, as well as the development and calculation of an effective attachment point for the building frame.

The study looks at two major approaches to improving earthquake resistance:

– a traditional method involving increasing the cross-sections of structures;

– a special method for reducing the load by changing the dynamic scheme of the structure.

Special attention is paid to architectural, planning and structural solutions that make it possible to increase the earthquake resistance of buildings. Different types of energy absorbers are also studied that efficiently absorb the energy of seismic vibrations preventing the destruction of load-bearing structures.

The analysis of typical earthquake damage enables ways and methods for increasing the earthquake resistance of a building to be formulated:

- reduction of inertial loads during seismic action due to the use of lightweight and efficient building materials;
- uniform and symmetrical distribution of stiffness and mass relative to building axes;
- location of butt joints outside the areas of greatest effort;
- ensuring the plastic operation of structures to absorb the energy of seismic impacts.

The study also examines modern active seismic protection systems, including seismic insulation, adaptive systems, damping and vibration dampers.

Special attention is paid to the development and analysis of the attachment point of the frame using a curved thin-walled plate. This solution makes it possible to effectively transfer forces from seismic impacts and ensure high earthquake resistance of the building.

Hence this study seeks to develop innovative design solutions increasing the reliability of buildings and structures, to create conditions for reducing possible damage including that to load-bearing structures.

Considering the typical earthquake damage, buildings and structures in regions with seismic activity of 8, 9, and 10 points should be designed so that the impact of seismic force is kept to a minimum. The aim of the study is to investigate the existing options for protecting buildings from seismic effects, as well as to calculate a possible attachment point for the building frame.

Materials and Methods. There are two ways to increase seismic resistance: traditional one— by increasing the cross-sections of structures and a special one — by reducing the load by means of changing the dynamic scheme of the structure [1].

The major ways of increasing the earthquake resistance of buildings are architectural planning and design solutions[1], as well as a range of energy-absorbers.

Based on the results of an engineering analysis of the effects of earthquakes, the following principles of earthquake-resistant buildings design were obtained [2]:

– reduction of seismic forces due to the use of lighter and more efficient building materials, thereby reducing the mass of structures;

– optimization of bending stiffness, the location of nodal masses equally distant, including symmetrically, in the most dangerous directions of seismic load;

– positioning / butt joints outside the area of greatest effort;

– ensuring the plastic operation of structures.

The standards for the design of steel structures allow the use of plastic properties. These properties can also be used for reducing the energy transferred to structures during seismic action. Such special elements are called energy absorbers. At the same time, additional design solutions to, e.g., increase rigidity, strength, and stability will not be required. If the yield point is exceeded, the energy absorbers can be replaced with no loss of structural performance [3, 4].

There are a few major types of energy absorbers in the literature. These include rods or plates used in frame systems characterized by low energy consumption; rings or pipes — as a rule — typically installed in connections to transfer stretching and compression forces through braces, bolted joints are used; beams are used instead of diagonal connections, energy absorption is provided due to the bending or torsional rigidity of the element; structures providing shift are characterized by a relatively high specific energy consumption.

In order to eliminate stress concentrations, structural elements should not include sudden changes in cross-sections for increasing cyclic strength and durability [5].

The issue of developing active seismic protection systems is relevant. The basic principles of such systems are the overall self-isolation of buildings or individual elements adaptive systems with variable characteristics, dampers and vibration dampers are used for [6].

Research Results. The simplest and most effective example of such an energy absorber can be a shape made of a bent thin-walled plate installed in the junction of the bond with the column with an offset relative to the axis of the bond. At the same time, the shape enables a transfer the forces from the seismic impact within the elastic operation of the material. Fig. 1 shows a diagram of the attachment point of the frame bond, Fig. 2 shows section 1–1.

[1] SP 14.13330.2014 Construction in Seismic Areas. Updated Edition of SNiP II-7-81*. Moscow: Standartinform; 2018. 114 p.

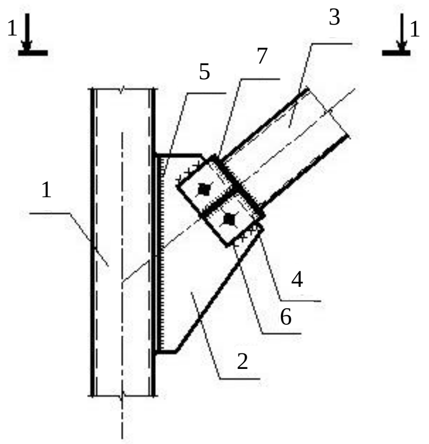

Fig. 1. Diagram of the attachment point of the frame bond

1–1

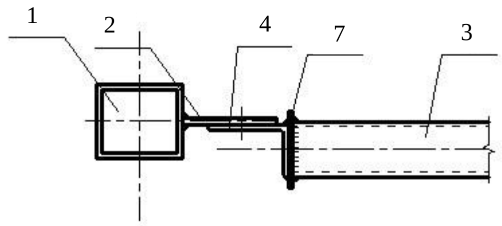

Fig. 2. Section 1–1

1. A coupling element 3 is attached to the column of the frame 1 having a shape 2. Fastening of the coupling element 2 to the column 1 is provided using factory welds 5. Fastening of the coupling element 4 of the bond 3 to the shape 2 is provided using bolts and mounting welding 6. Fastening of the coupling element 4 is provided through the plug 7 of the coupling element 3 from a closed bent-welded the profile.

2. Forces from the coupling element 3 to the column 1 are transferred through the shape 4 attached with an offset relative to the axis of the coupling 3. The node operates as follows: the shape 4 perceives the forces from the coupling element 3, while elastically deforming, due to ductility reduces the internal forces transmitted to the column 1. The operation in the elastic area does not lead to residual deformations and ensures sufficient reliability of the attachment point of the bond with the column.

3. While exposed to a horizontal seismic load, there are elastic deformations in the profile 4 at the junctions of the bond 3 with the column 1, due to which a significant part of the vibrations is absorbed increasing the seismic stability of the building.

4. A finite element analysis of the stress-strain of the shape under a compressive force has been performed via the Stark ES software package. The main stresses and deformations in the element are identified. The calculation scheme is shown in Fig. 3, the voltage distribution is shown in Fig. 4. The essence of the finite element method is that the calculated structure is divided into a number of small but finite elements, which, depending on the type of structure and the nature of its deformation, might have different shapes. An example of calculation using this method is discussed in [7], where the research model is a freely supported single-span beam made of a thin-walled profile with a channel section. Isotropic plates with a thickness of 1.2 mm are used as the finite elements.

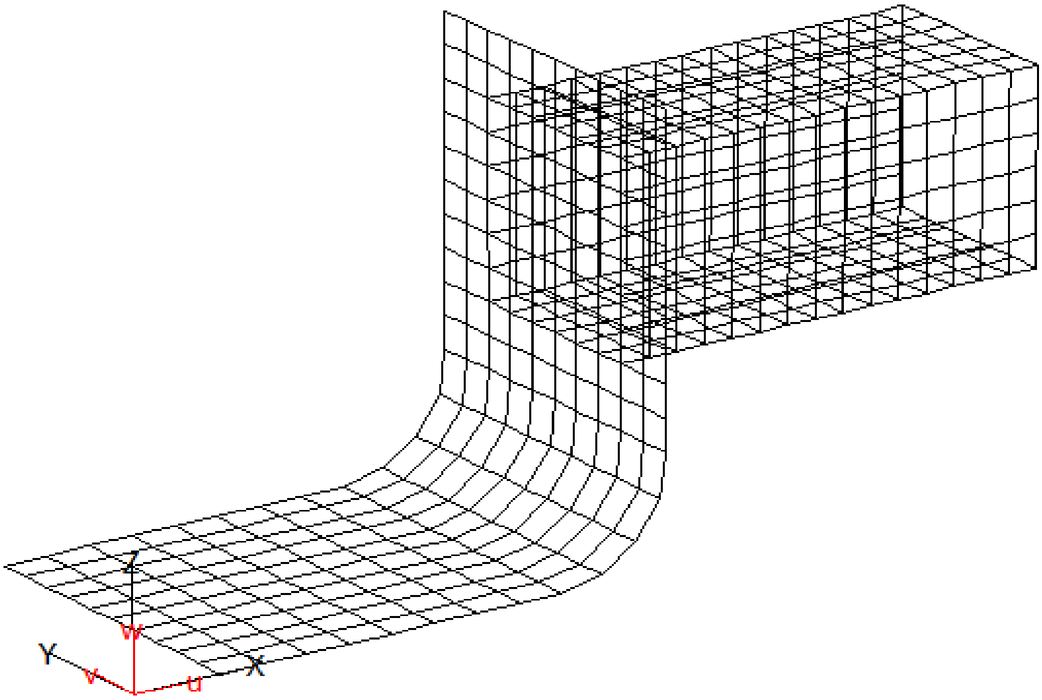

Fig. 3. Calculation scheme

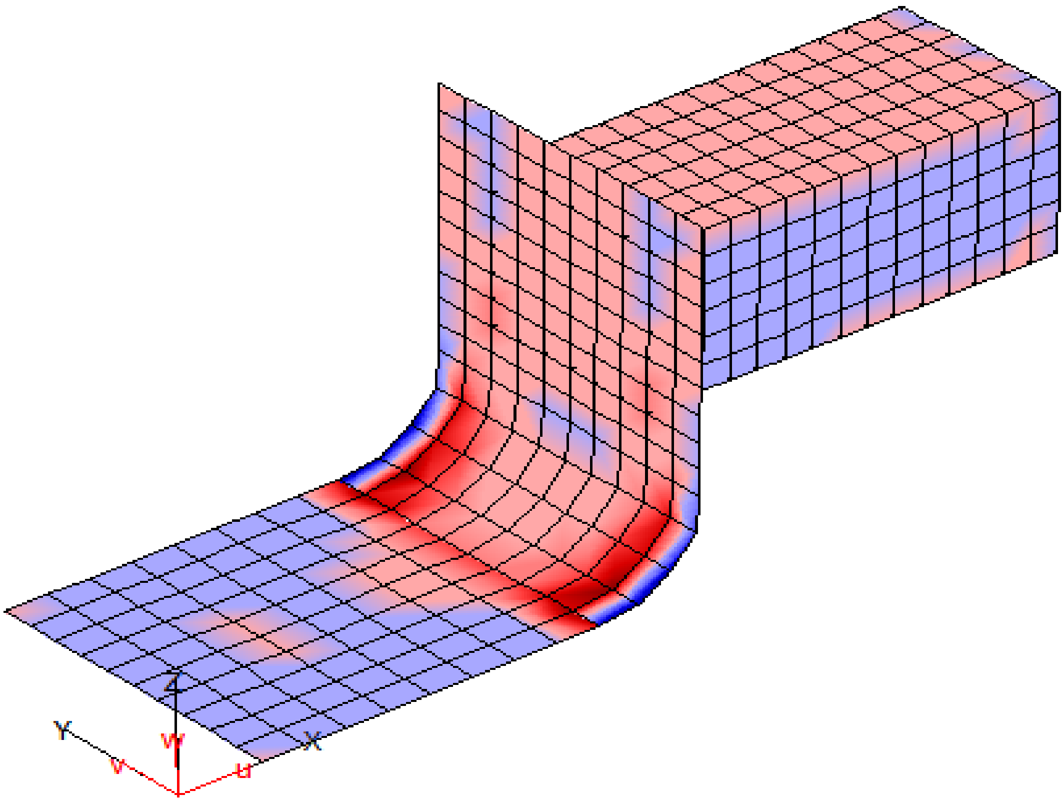

Fig. 4. Main stresses in the gusset

5. The frame structure is easy to manufacture, reduces metal consumption, provides high seismic stability, and is easily replaced with a new one allowing quick complete restoration of the bearing capacity of the frame.

Discussion and Conclusion. As a result of the study, innovative design solutions have been set forth in order to increase the earthquake resistance of buildings. These include the use of energy-absorbing shapes made of bent thin-walled plates in the attachment points of the frame bonds.

The application of the suggested constructive solutions allows one:

– to reduce the metal consumption of structures;
– to ensure easy replacement of elements if needed;
– to scale the solutions for different types of building structures and climatic conditions.

Therefore the resulting solutions are a critical contribution to the development of earthquake-resistant construction and can be successfully applied in a wide range of regions experiencing an increased seismic activity.

References

1. Sinitsyn SB Earthquake Resistance Theory: a Course of Lectures. Moscow: MGSU; 2014. 88 p. (In Russ.)

2. Martemyanov AI *Design and Construction of Buildings and Structures in Earthquake-Resistant Areas: a Textbook for Universities.* Moscow: Stroyizdat; 1985. 255 p. (In Russ.)

3. Ostrikov GM, Maksimov YuS *Steel Earthquake-Resistant Frames of Multi-Storey Buildings.* Alma-Ata: Kazakhstan; 1985. 120 p. (In Russ.)

4. Kochetov OS *Earth-Resistant Structure of a Building.* RF Patent № RU 2020 106 976. 2021. 2 p.

5. Semenov VS, Tokarskiy AV, Alferova TP Energy Absorders in Steel Frames of Earthquake-Resistant Buildings. *Herald of KRSU.* 2016;16(5):136–139. (In Russ.) URL: http://vestnik.krsu.edu.kg/archive/38/1678 (accessed: 28.05.2025).

6. Chigrinskaya LS Earthquake Resistance of Buildings and Structures: a Textbook. Angarsk: AGTA; 2009. 107 p. (In Russ.)

7. Skachkov SV Features Calculation of Structures of Thin-Walled Steel Profiles. *Naukovedenie.* 2012;3:1–6. (In Russ.) URL: https://naukovedenie.ru/sbornik12/12-118.pdf (accessed: 28.05.2025).

About the Authors:

Maria P. Kotenko, PhD student of Rostov State Transport University (2 Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya Sq., Rostov-on-Don, 344038, Russian Federation), ORCID, maria.kotencko2016@yandex.ru

Sergey V. Skachkov, Cand.Sci. (Eng.), Associate Professor of the Department of Metal, Wood and Plastic Structures, Don State Technical University (1 Gagarin Sq., Rostov-on-Don, 344003, Russian Federation), ORCID, sskachkov@donstu.ru

Claimed contributorship:

SV Skachkov: study of existing options for protecting buildings from seismic effects, study of various energy sinks and active seismic protection systems, as well as the development of constructive solutions to improve the earthquake resistance of buildings.

MP Kotenko: development of the content and concept of the manuscript, substantiation of the conclusions.

Conflict of interest statement: **the authors do not have any conflict of interest.**

All authors have read and approved the final version of manuscript.

Об авторах:

Котенко Мария Павловна, аспирант Ростовского государственного университета путей сообщения (344038, Российская Федерация, г. Ростов-на-Дону, пл. Ростовского Стрелкового Полка Народного Ополчения, 2), ORCID, maria.kotencko2016@yandex.ru

Скачков Сергей Владимирович, кандидат технических наук, доцент кафедры металлических, деревянных и пластмассовых конструкций Донского государственного технического университета (344003, Российская Федерация, г. Ростов-на-Дону, пл. Гагарина, 1), ORCID, sskachkov@donstu.ru

Заявленный вклад соавторов:

С.В. Скачков: исследование существующих вариантов защиты зданий от сейсмического воздействия, изучение различных энергопоглотителей и систем активной сейсмозащиты, а также разработка конструктивных решений для повышения сейсмостойкости зданий.

М.П. Котенко: разработка содержания статьи, концепция статьи, обоснование выводов.

Конфликт интересов: **авторы заявляют об отсутствии конфликта интересов.**

Все авторы прочитали и одобрили окончательный вариант рукописи.

Received / Поступила в редакцию 06.06.2025
Revised / Поступила после рецензирования 20.06.2025
Accepted / Принята к публикации 07.07.2025