Строительство уникальных зданий и сооружений. ISSN 2304-6295. 9 (24). 2014. 97-105

Construction of Unique Buildings and Structures

journal homepage: www.unistroy.spb.ru

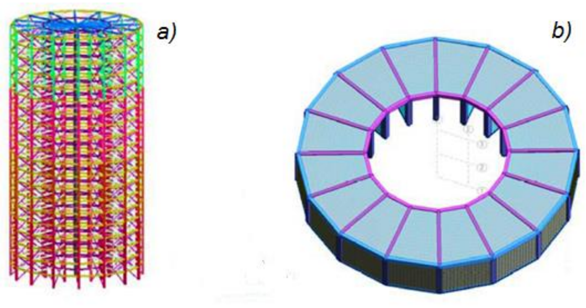
Design of load bearing structure of multilevel automated car garage

K. Runevski[1]

Institute of Earthquake Engineering and Seismology, 165 Todor Aleksandrov, 165, 1000, Skopje, Republic of Macedonia.

ARTICLE INFO	Article history	Keywords
Technical paper	Received 10 September 2014 Accepted 23 September 2014	car garage, bearing structure, ring plan, steel, reinforced concrete, design

ABSTRACT



This paper is a part of a graduation thesis that was presented at the Faculty of Civil Engineering in Skopje. The subject of this thesis is design of a load bearing structure of an automated car garage. It is a multi storey structure with a ring plan. In its middle part, there is a central column resting at the level of the basement plate and the roof structure level. The part of the structure above ground is designed as steel braced frame structure, while the part below ground as a reinforced concrete structure composed from frames and walls. Static analysis of a 3D mathematical model was performed by use of the Autodesk Robot Structural Analysis Professional software.

Contents

1 *Corresponding author:*
kristijanr@pluto.iziis.ukim.edu.mk (Kristian Runevski , Post-graduate student)

1. Introduction

The development of motorization has caused many social problems with parking and garaging cars especially in big urban areas, there the number of vehicles has constantly been increasing. This problem is particularly topical in urban centers with no free surfaces for construction of facilities covering large areas since in those parts; the price of land is quite high so that construction of parking of a traditional type is not economically justified. Therefore, there is a need for a more advanced solution to this problem. One of these solutions is the construction of a special type of garages where parking is completely automatic. The driver parks his vehicle in front of the building where the automatic system takes it so that motion, lifting and parking is controlled by a computer. For vertical transport, there are elevators which are fixed to the column in the center of the building. In addition to vertical transport, they also move in a horizontal direction so that they can park or pull a vehicle out from a parking place. Such a concept enables greater number of storey, and parking of a large number of vehicles on a small plan [1-22].

2. Project parameters

Project documentation has been prepared by taking into consideration some geometric parameters that are necessary for good functioning of the facility:

- Free storey height - 2.0m
- Radial distance between an inner and outer column - 6.0m
- Free radial distance from the central column to the inner perimeter columns 6.5m
- Width of footpaths - 0.5m
- Number of parking places at one level - 16
- Number of store’s - 20

Project requirements related to loads for static and dynamic analysis were taken from the Macedonian regulations on loading of buildings [2]:

- Vehicle load - 2x15kN
- Remaining dead load of beams for vehicles - 2x6.65kN
- Snow - (620mNV) [6]
- Wind - (II zone of winds, exposed building) [3]
- Seismic load - (IX zone of seismic activity, I category structure, II soil class) [4]
- Allowable bearing capacity in soil - 240kPa.

The dead weight of the structural elements was applied as a separate load case, manually on the model, based on preliminary computation of geometrical characteristics of elements.

Materials used in the design of the structure:

- Steel - S235;
- Concrete - MB30;
- Reinforcement bars - RA400/500-2.

3. Technical description

The designed object represents an automated parking garage with a plan in the form of a ring. The building is divided into two structural units: steel and reinforced concrete. The whole structure is modular, with disposition of the modules radially to the central axis of the structure.

The part of the building above the ground is designed as a steel frame system with diagonals, positioned in vertical and horizontal planes. The bearing capacity regarding vertical loads is provided by 32 columns of HEA profiles, positioned radially in two concentric circles with a diameter of 14.0 and 26.0m, respectively. The angle between two adjacent columns is 22.5^{o}. Horizontal stiffness of the structure is achieved by mutual stiffening of the columns by beams and diagonals. The frames are interconnected by end beams in the inner and outer diameter of the columns. The connection between the columns and beams is designed as fixed, which is achieved by welding. At every second level, there is a horizontal bracing, which enables better interaction between the horizontal and the vertical elements of the structure. The central part of the building is open without structural elements, from the level of the floor slab of the basement to the roof. This open space is with a diameter of 14.0m. In the center of the building, there is a central column (round tube) O1016.16 that is hinged at the floor slab and roof structure levels. Upon this column, there are rails for motion of the two platforms (elevators) for transport of the vehicles in vertical and horizontal direction. The geometrical characteristics of the columns vary along height. At each fifth storey, there is a change of the geometrical cross section (HEA400, HEA340, HEA300, HEA240). Connection of the columns is done by a front plate representing a precast unit welded to the lower column. Upon it, the upper column is welded. All columns along height are displaced from the central axis so we have a flat surface on one side of the column. The columns of outer diameter are displaced to the outside, while the columns of the inner diameter are displaced to the inside, looking from the central axis outward. The columns are connected by beams and the connection between them is designed as fixed. Cold formed I profiles are used:

Beams in the outer perimeter - IPE270
Beams in the inner perimeter - IPE200
Radial beams - IPE240
Roof beams - IPE300
Bracing is designed with cold formed square tubes, which are pinned to the other elements of the structure:
Vertical bracing - SHSH 100.10
Horizontal bracing - SHSH 60.6

The building above ground has 20 levels with equal storey height of 2.20 m. The height of the structure to the cornice is 44.09m, while the height to the top is 44.71m. In the horizontal section of the building the radial distance between the end columns is 26.0m, while the distance between the inner columns is 14.0m.

Considering that, in the middle, there is a round column with a diameter of 1016mm, the distance between the inner and the middle columns is 6.50m, whereat the width of the footpaths (0.50m) is subtracted and the final free distance is 6.0m. Below ground, there is one level with a height of 3.0m. The elevation of the floor plate is -3.03m, while the foundation is at an elevation -3.93m. The entire structure below ground is designed as reinforced concrete, i.e., a mixed system of frames and walls. Reinforced concrete walls with thickness of 20cm are used along the perimeter of the structure, and also radial between the corresponding columns. Under each steel column, a reinforced concrete column proportioned 45x55cm is constructed. The connection between the two structures is designed as hinged by means of 4 anchors Φ30 with length of 800mm, positioned inside the steel column. At the ground floor, there is a concrete slab with a thickness of 15cm. Similar to the remaining structure, it has an opening with a diameter of 14.0 m in the middle enabling free motion of the platforms with the vehicles. The foundation of the building is designed to have beams (65x90cm) in two directions, radial and tangential. In the middle, all radial beams overlap so that this part with a diameter of 4.0 m is planned to be designed as a foundation slab.

4. Analysis and design of construction

Static analysis of the building was carried out by use of the Autodesk Robot Structural Analysis Professional software package. For this purpose, two mathematical models were used, one for the steel structure and one for the reinforced concrete structure. It was considered that this approximation would not yield a big difference in results compared to the actual behavior of the structure when analyzed as a single model.

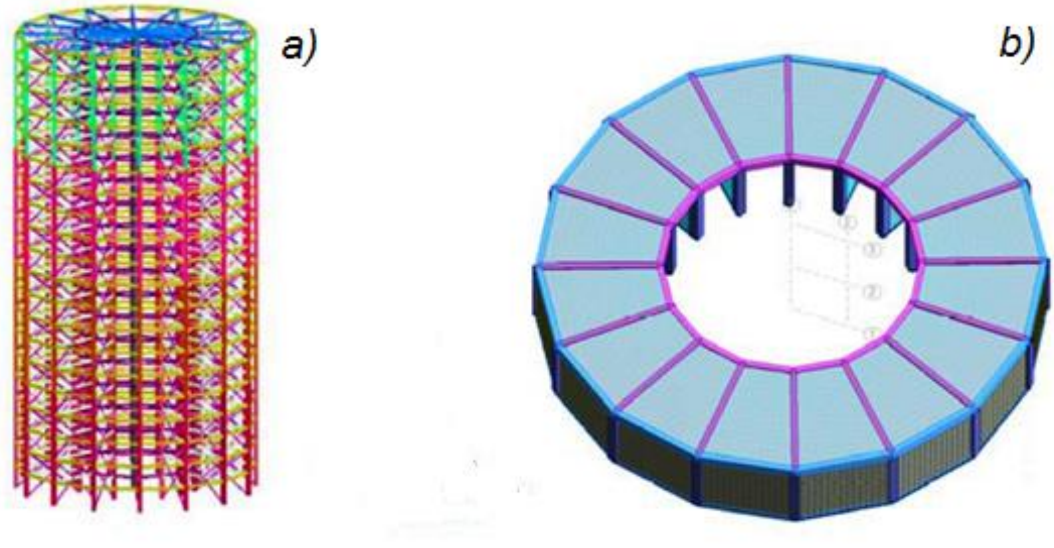


Figure 1. 3D view of the mathematical model a) steel structure, b)concrete structure.

First, the steel construction was designed. It was modeled as hinged to the ground. Because only linear structural elements were used, no finite element analysis was required. Based on load analysis, few load cases were applied on the model. A modal analysis was performed, whereat a basic period of T = 1.49s was obtained. Taking into consideration. the type of the structure, we came to the conclusion that this value was expected. Based on the results of the modal analysis, a seismic load case was added. The analysis was done by applying a seismic force in one direction. This was possible because of the building is symmetrical. Seismic analysis was carried out according to the Macedonian regulations, i.e., by applying equivalent horizontal seismic force [4]. The total seismic force was Svk=1547kN. For the building with 20 floors, it was necessary that 15% of the total seismic force be applied on the top floor, while the rest of the force was distributed over the floors according to the following expression:

$$Si = S \frac{Gi \cdot hi}{\sum_1^{20} Gi \cdot hi} \tag{1}$$

Several possible loading combinations relevant for design of the structural elements were made. The choice of the geometrical cross section of the elements was made in an iterative way, by continuously controlling the maximum stress and displacement, taking care obtaining as economical as possible structure. Dimensioning of the structural elements was done by the elasic theory [5], according to the Macedonian regulations MKS. Considering that it is a relatively light structure without floor panels and with little value of life load, the actual stresses were quite lower than the allowed ones. After control of the second order, the maximum stress was reached in the columns of the ground, amounting to 45% of the allowed stresses for steel (21 kN/cm2 for the third load comb). It is important to control the allowed horizontal displacement. For this structure, the allowed displacement is Δdoz=8.0cm [4]. The maximum horizontal displacement due to combination of dead, life and seismic loads amounted to Δmax=7.9cm. Based on the values obtained from the mathematical model of the steel structure, the reinforced concrete structure was designed. The obtained responses of the previous model as well as the loads acting upon the reinforced concrete structure were applied on the new model. Since there were linear and surface structural elements in this model, finite element analysis was performed. The individual load cases were combined to obtain the ultimate static quantities for the proportioning of the reinforced concrete elements according to the theory of ultimate states. During proportioning, expected values of needed reinforcement were obtained as a proof that structural elements were properly adopted.

5. Project documentation

The graphical drawings for the steel structure were made by use of the Graitec Advance Steel software package. This is advanced software that has the capability of modeling the structure with all the details in 3D. Based on such a model, 2D drawings are generated. The advantage of this mode of elaboration of project documentation is that one model is sufficient to derive all necessary drawings for the construction of the structure and that the software also performs automatic marking and levelling. The software recognizes each change in the 3D model and applies the change on the ready 2D drawings. The software also provides the possibility of generation of specification of materials and list for procurement of material, yielding the exact value of the material necessary for the construction of the structure.

Above is presented a part of the graphic appendices from the design documentation providing a clear insight into the concept of functioning of the structure.. What is important to note is that the perimeter beams are placed eccentrically in respect to the axis of the columns. The reason for this is the need for a better esthetical appearance of the building. The beams from the outer perimeter will serve as facade beams and will sustain the load of the facade coating. The details show that the column together with the sheet metal plates processed in the form of I profile with widened flanges are welded as a precast unit in a workshop. On them, the beam of IPE profile will be welded. The beam is manufactured in such a way that the upper and the lower flange welds will be in a different place along the beam. The vertical sheet metal plates are properly processed allowing better shear resistance. The design of the concrete structure is done in a classical way. Below are presented characteristic plans of the ground floor and the foundation structure. During concreting of the columns, anchors that enable connection between the two structures are installed. The concrete structure is designed such that between the anchor plates of the steel columns and the concrete slab, there is a clearance of 3.0 cm that will be filled with epoxy mortar of high strength to provide a flat base for the anchor plates.

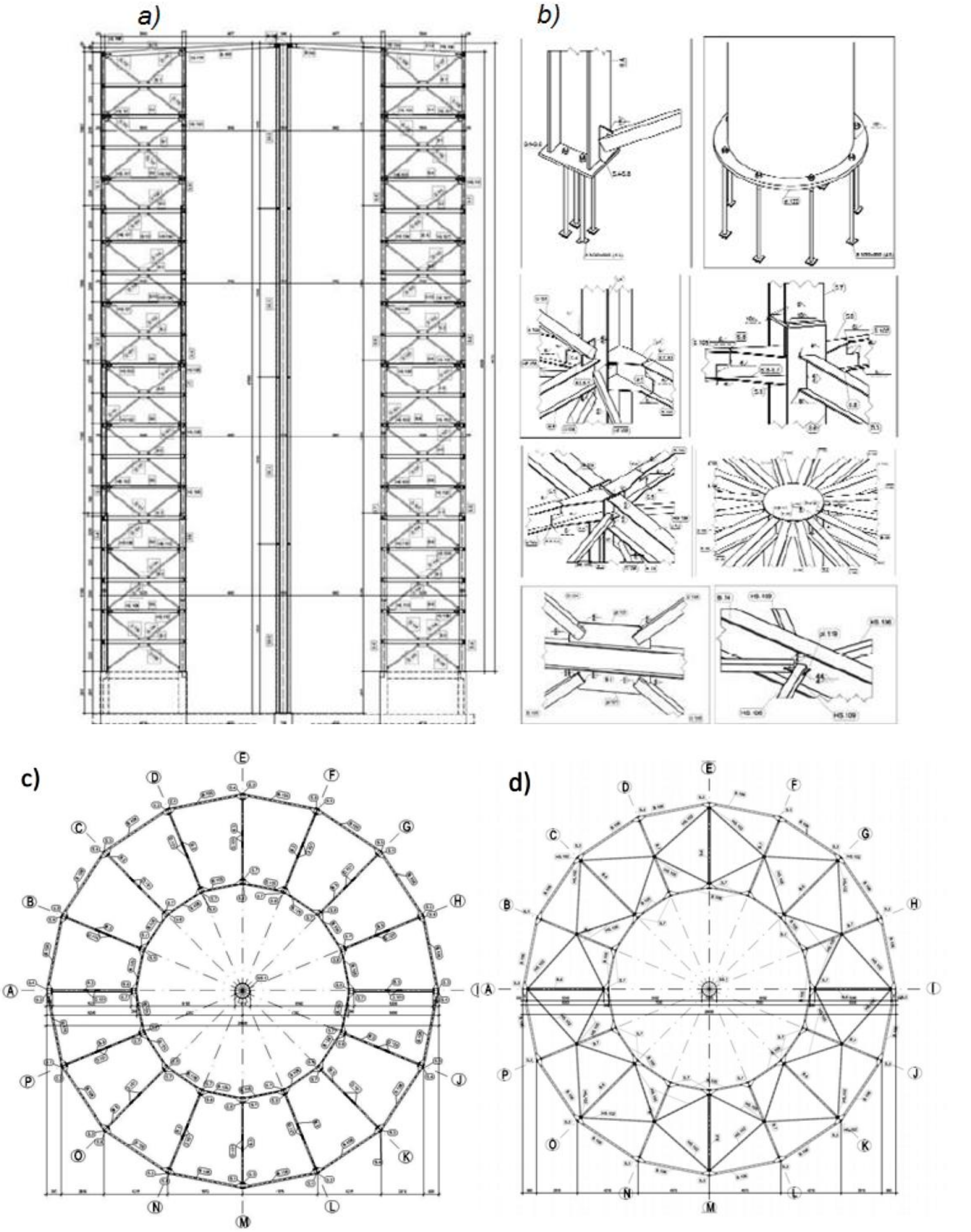


Figure 2. Steel structure: a) Vertical section, b) Typical 3D details, c) Disposition of the floor without horizontal diagonals, d) Disposition of the floor with horizontal diagonals

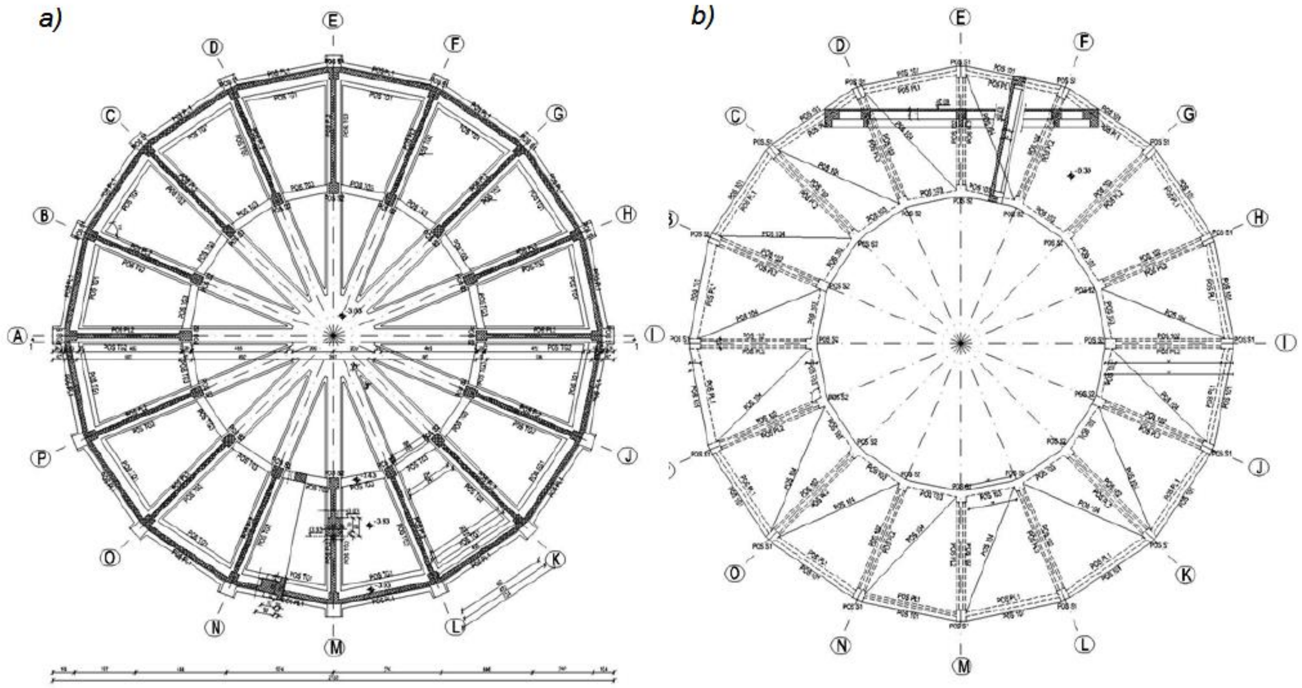


Figure 3. Concrete structure: a) Foundation plan, b) Ground floor plan.

6. Conclusion

This paper provides a brief description of the design of an unusual structure from both structural and functional point of view. During the design of this building, all standards and recommendations valid in the R. Macedonia were observed. Considering that this is a very high structure with small amount of loads, it is concluded that no questions could be raised regarding its bearing capacity. However, it is necessary to also check the maximum displacements that are competent in the design of this structure.

Based on the bill of quantities, the following amounts of material are needed:
Steel – 393898 kg
Concrete – 317 m^3
Reinforcement bars – 45338 kg
Anchors 136Ф30 L=800 mm

From this data, a conclusion can be drawn that the construction of the bearing structure would be far less costly in respect to the classical reinforced concrete and steel storey garages. Considering that the number of storey is practically unlimited by the users of the structure, this means that a far greater number of storey could be designed, meaning a much greater number of vehicles per unit of area compared to the classical types of storey garages. This type of facilities is quite acceptable for the drivers because parking ends in front of the building thus saving time and fuel. The cost of the automatic system that could exceed the cost of the classical type could be a major disadvantage of these facilities. It is the sophisticated equipment that requires a much resources for maintenance. The capacity of the two platforms could also be limited in conditions when there is a greater need for parking, i.e., a certain delay could take place in critical periods of the day when there are more users.

References

[1]. Runevski K. Analysis and design of load bearing structure of automated car garage (in Macedonian), Gradutation thesis, Skopje, 2013. p. 180

[2]. Cvetanovski P. Design of Steel Structures" (in Macedonian), Faculty of Civil Engineering, 2014. 231 p.

[3]. *Jugoslovenski standard: Opterecenje vjetrom*, JUS U.C7.110, JUS U.C7.111 I JUS U.C7.112ю

[4]. *Pravilnik o tehnickim normativima za izgradnju objekata visokogradnje u seizmickim podrucjima*, 1981. 168 p.

[5]. Filipovski G. Steel Structures, (in Macedonian), Faculty of Civil Engineering - Skopje, Skopje, 2000. p. 382

[6]. Atanasovski S.. Design of Reinforced Concrete, (in Macedonian), Faculty of Civil Engineering, Skopje, 2000. p. 385

[7]. Vatin N. I., Gorshkov A. S., Nemova D. V. Energy efficiency of envelopes at major repairs (2013) Construction of Unique Buildings and Structures. 3 (8). pp. 1-11.

[8]. Gorshkov A. S., Vatin N. I., Nemova D. V. The energy saving formula, Energy efficiency of envelopes at major repairs (2013) Construction of Unique Buildings and Structures. 7 (12). pp. 49-63.

[9]. Platonova M. A., Vatin N. I., Nemova D. V., Matoshkina S. A., Iotti D., Togo I. The influence of the airproof composition on the thermo technical characteristics of the enclosing structures (2014) Construction of Unique Buildings and Structures. 4 (19). pp. 83-95.

[10]. Flager F., Soremekun G., Adya A. Fully Constrained Design: A general and scalable method for discrete member sizing optimization of steel truss structures (2014) Computers & Structures. Vol. 140. pp. 55-65.

[11]. Zhang H., Rasmussen J.R. System-based design for steel scaffold structures using advanced analysis (2013) Journal of Constructional Steel Research. Vol. 89. pp. 1-8

[12]. Kravanja S., Turkalj G., Šilih S., Žula T. Optimal design of single-story steel building structures based on parametric MINLP optimization (2013) Journal of Constructional Steel Research. Vol. 81. pp. 86-103.

[13]. Gunalan Sh., Heva Y. B., Mahendran M. Flexural–torsional buckling behaviour and design of cold-formed steel compression members at elevated temperatures. (2014) Engineering Structures. Vol. 79. pp. 149-168.

[14]. Theofanous M., Saliba N., Zhao O., Gardner L. Ultimate response of stainless steel continuous beams (2014) Thin-Walled Structures. Vol. 83. pp. 115-127.

[15]. Shu G., Zheng B., Xin L. A new design method for stainless steel columns subjected to flexural buckling. (2014) Thin-Walled Structures. Vol.83. pp. 43-51

[16]. .Vatin N.I., Sinelnikov A.S. Vatin N.I., Sinelnikov A.S. Long span footway bridges: coldformed steel cross-section (2012) Construction of Unique Buildings and Structures. Issue 1. pp. 47-53.

[17]. Kishinevskaya Ye. V., Vatin N. I., Kuznetsov V. D. *Perspektivy primeneniya nanobetona v monolitnykh bolsheproletnykh rebristykh perekrytiyakh s postnapryazheniyem* [Application of nanoconcrete in post-stressed monolithic span ribbed slabs] (2009) Magazine of Civil Engineering. 2. pp. 54-58.

[18]. Urbanavičienė V., Kaklauskas A., Zavadskas E. K., Šliogerienė J., Naimavičienė J., Vatin N. I. Facilitating the housing bargaining with the help of the bargaining decision support system (2014) International Journal of Strategic Property Management. 18 (3). pp. 213–225.

[19]. Xin H., Liu Y., He J., Zhang Y. Experimental and analytical study on stiffened steel segment of hybrid structure. , (2014) Journal of Constructional Steel Research, Vol. 100. pp. 237-258.

[20]. Chan S.L. Non-linear behavior and design of steel structures (2001) Journal of Constructional Steel Research, Vol. 57, pp. 1217-1231

[21]. Saadat S., Camp Ch. V., Sh. Pezeshk. Seismic performance-based design optimization considering direct economic loss and direct social loss (2014) Engineering Structures, Vol. 76. pp. 193-201

[22]. Liu M., Wen Y.K., Burns S. A. Life cycle cost oriented seismic design optimization of steel moment frame structures with risk-taking preference (2004). Engineering Structures. Vol. 26. Issue 10. pp.1407-1421.

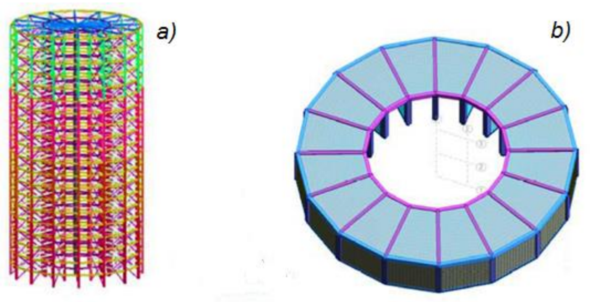
Проектирование несущих конструкций многоуровневого автоматизированного гаража

К. Руневски[1]

Институт сейсмостойкого строительства и сейсмологии, Тодор Александров, 165, 1000, Скопье, Республика Македония.

Информация о статье	**История**	**Ключевые слова**
УДК 69 Научная статья	Подана в редакцию 10 сентября 2014 Принята 23 сентября 2014	автомобильный гараж, круглый план, несущие конструкции, сталь, железобетон, проектирование

АННОТАЦИЯ



Статья представляет собой выдержку из дипломной работы, представленной на факультете Гражданского строительства в г. Скопье. Дипломная работа посвящена проектированию несущих конструкций многоэтажного автоматизированного гаража. Статический анализ 3D-математической модели выполнен с использованием программного обеспечения Autodesk Robot Structural Analysis Professional.

[1] *Контактный автор:*
kristijanr@pluto.iziis.ukim.edu.mk (Руневски Кристиан , аспирант)

Литература

[1]. Runevski K. Analysis and design of load bearing structure of automated car garage (in Macedonian), Gradutation thesis, Skopje, 2013. p. 180

[2]. Cvetanovski P. Design of Steel Structures" (in Macedonian), Faculty of Civil Engineering, 2014. 231 p.

[3]. *Jugoslovenski standard: Opterecenje vjetrom*, JUS U.C7.110, JUS U.C7.111 I JUS U.C7.112ю

[4]. *Pravilnik o tehnickim normativima za izgradnju objekata visokogradnje u seizmickim podrucjima*, 1981. 168 p.

[5]. Filipovski G. Steel Structures, (in Macedonian), Faculty of Civil Engineering - Skopje, Skopje, 2000. p. 382

[6]. Atanasovski S. Design of Reinforced Concrete, (in Macedonian), Faculty of Civil Engineering, Skopje, 2000. p. 385

[7]. Ватин Н. И., Горшков А. С., Немова Д. В. Энергоэффективность ограждающих конструкций при капитальном ремонте (2013) Строительство уникальных зданий и сооружений. 2013. №3 (8). С. 1-11.

[8]. Горшков А. С., Немова Д. В., Ватин Н. И. Формула энергоэффективности // Строительство уникальных зданий и сооружений. 2013. 7 (12). С. 49-63.

[9]. Платонова М.А., Ватин Н.И., Немова Д.В., Матошкина С.А., Иотти Д., Того И. Влияние воздухоизоляционного состава на теплотехнические характеристики ограждающих конструкций. // Строительство уникальных зданий и сооружений. №4 (19). С. 83-95.

[10]. Flager F., Soremekun G., Adya A. Fully Constrained Design: A general and scalable method for discrete member sizing optimization of steel truss structures (2014) Computers & Structures. Vol. 140. pp. 55-65.

[11]. Zhang H., Rasmussen J.R. System-based design for steel scaffold structures using advanced analysis (2013) Journal of Constructional Steel Research. Vol. 89. pp. 1-8

[12]. Kravanja S., Turkalj G., Šilih S., Žula T. Optimal design of single-story steel building structures based on parametric MINLP optimization (2013) Journal of Constructional Steel Research. Vol. 81. pp. 86-103.

[13]. Gunalan Sh., Heva Y. B., Mahendran M. Flexural–torsional buckling behaviour and design of cold-formed steel compression members at elevated temperatures. (2014) Engineering Structures. Vol. 79. pp. 149-168.

[14]. Theofanous M., Saliba N., Zhao O., Gardner L. Ultimate response of stainless steel continuous beams (2014) Thin-Walled Structures. Vol. 83. pp. 115-127.

[15]. Shu G., Zheng B., Xin L. A new design method for stainless steel columns subjected to flexural buckling. (2014) Thin-Walled Structures. Vol.83. pp. 43-51

[16]. Ватин Н.И., Синельников А.С. Большепролетные надземные пешеходные переходы из легкого холодногнутого стального профиля // Строительство уникальных зданий и сооружений. 2012. № 1. С. 47-53.

[17]. Кишеневская Е.В., Ватин Н.И., Кузнецов В.Д. Перспективы применения нанобетона в монолитных большепролетных ребристых перекрытиях с постнапряжением // Инженерно-строительный журнал. 2009. №2. С. 54-58.

[18]. Urbanavičienė V., Kaklauskas A., Zavadskas E. K., Šliogerienė J., Naimavičienė J., Vatin N. I. Facilitating the housing bargaining with the help of the bargaining decision support system (2014) International Journal of Strategic Property Management. 18 (3). pp. 213–225.

[19]. Xin H., Liu Y., He J., Zhang Y. Experimental and analytical study on stiffened steel segment of hybrid structure. , (2014) Journal of Constructional Steel Research, Vol. 100. pp. 237-258.

[20]. Chan S.L. Non-linear behavior and design of steel structures (2001) Journal of Constructional Steel Research, Vol. 57, pp. 1217-1231

[21]. Saadat S., Camp Ch. V., Sh. Pezeshk. Seismic performance-based design optimization considering direct economic loss and direct social loss (2014) Engineering Structures, Vol. 76. pp. 193-201

[22]. Liu M., Wen Y.K., Burns S. A. Life cycle cost oriented seismic design optimization of steel moment frame structures with risk-taking preference (2004). Engineering Structures. Vol. 26. Issue 10. pp.1407-1421.