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ПОРІВНЯННЯ ЕФЕКТИВНОСТІ ПРОГРАМНИХ КОМПЛЕКСІВ LIRA 9.6 ТА SAP2000 ПРИ ДИНАМІЧНОМУ РОЗРАХУНКУ ВИСОТНОГО ОБ'ЄКТА

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Анотація. У статті розглядається питання зіставлення двох скінченно-елементних програмно-обчислювальних комплексів: Ліра-САПР версії 9.6 і SAP2000 версії 14.1. За досліджувані конструкції для зіставлення на першому етапі прийняті консольно-затиснені в основі металеві стійки різного поперечного перерізу, на другому етапі – просторова металева ґратчаста башта висотою 180 м. Моделі вищезазначених конструкцій були побудовані в обох програмах. Виконано динамічний розрахунок моделей на дію синусоїдального навантаження величиною 1 кН і отримані параметри напружено-деформованого стану конструкцій, що підлягають зіставленню, а саме: переміщення верхніх вузлів систем та зусилля в опорних перерізах систем. Виконано порівняльний аналіз отриманих параметрів від розрахунку обома програмами і визначено відсоток зіставності значень даних параметрів.

Ключові слова: програмно-обчислювальні комплекси Lira 9.6 і SAP2000, динамічний розрахунок, металеві конструкції, башта, переміщення, зусилля, порівняльний аналіз, розрахункова модель.

СРАВНЕНИЕ ЭФФЕКТИВНОСТИ ПРОГРАММНЫХ КОМПЛЕКСОВ LIRA 9.6 И SAP2000 ПРИ ДИНАМИЧЕСКОМ РАСЧЕТЕ ВЫСОТНОГО ОБЪЕКТА

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Аннотация. В статье рассматривается вопрос сопоставления двух конечно-элементных программно-вычислительных комплексов: Лира-САПР версии 9.6 и SAP2000 версии 14.1. В качестве исследуемых конструкций для сопоставления на первом этапе приняты консольно-защемленные в основании металлические стойки различного поперечного сечения, на втором этапе – пространственная металлическая решетчатая башня высотой 180 м. Модели вышеупомянутых конструкций были построены в обеих программах. Выполнен динамический расчет моделей на действие синусоидальной нагрузки величиной 1 кН и получены параметры напряженно-деформированного состояния конструкций, подлежащие сопоставлению, а именно: перемещения верхних узлов систем и усилия в опорных сечениях систем. Выполнен сопоставительный анализ полученных параметров от расчета обеими программами и определен процент сопоставимости значений данных параметров.

Ключевые слова: программно-вычислительные комплексы Lira 9.6 и SAP2000, динамический расчет, металлические конструкции, башня, перемещения, усилия, сравнительный анализ, расчетная модель.

COMPARISON OF EFFICIENCY OF LIRA 9.6 AND SAP2000 PROGRAM COMPLEXES IN THE DYNAMIC CALCULATION OF HIGH-RISE OBJECT

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Abstract. The issue of comparison of two finite-element computing complexes: Lira-CAD version 9.6 and SAP2000 version 14.1 is discussed in the article. As investigated structures for comparing the cantilever struts of different cross-section were taken in the first stage, and the spatial latticed steel tower of 180 m height in the second stage. The models of mentioned above structures were built in both programs. The dynamic calculation of models on action of sinusoidal load of 1 kN was performed and parameters of the stress-strain state of structures to be compared: the displacements of upper joints and efforts in support sections of the structures were obtained. A comparative analysis of parameters obtained by calculation in both programs was performed and the percentage of comparability of the values of these parameters was determined.

Keywords: computing complex, Lira 9.6; SAP2000, dynamic analysis, metal structures, tower, movements, efforts, comparative analysis, calculation model.

Formulation of the problem

Designing a building or structure – this is without a doubt a very laborious process that requires considerable time and effort, but it is also a very important process, because of the quality performance of the design stage depends the safety and life time of the future building or structure. At a time when the buildings were low-rise and the methods of calculation were primitive, it almost was not difficult for engineers to calculate the structures of the building by hand. Over time, the construction has evolved, the design systems of buildings and structures became more complex, the objects themselves have increased in volume and height, there is a need for material savings that is why more complicated methods of calculation were appearing, and manual calculation was becoming more complex and time-consuming process. With the invention of computer a computing machinery came to the aid to engineers. It could perform the same complex calculations in much less time, no doubt facilitated the design process and the work of the designer.

Today it is difficult to imagine the process of designing a building or structure without the use of specialized computer programs because the objects have become so large and complex that it is impossible to calculate them by hand, or it would take an incredible amount of time. On the market today there are many software and computing complexes from various manufacturers, among which are the ANSYS, Lira-CAD, SCAD, SAP2000, NASTRAN, PLAXIS and others. All of them allow you to solve a huge range of design tasks, which greatly facilitate the work of engineers, designers and design phase of the object as a whole, while providing higher accuracy and less error probability compared to manual calculation, of course, with the correct input of source data.

However, despite the fact that all computing complexes operate on the basis of finite element method (FEM), because of the different approaches to programming and accepted hypotheses (tolerances, national features of methods, rounding the results, etc.) the results of calculations in computing complexes of various manufacturers may vary. So interesting and important is the comparison of calculation modules of different computing complexes to identify more rational computing complex to perform various engineering tasks, as well as to improve the quality of the calculation justifications of design decisions by calculating of structure based on several programs simultaneously.

By the way, last proposal, according to A. V. Ioskevich [1], was made by the Main State Expertise in Russia in 2004: «... to carry out calculations at least on two certified, independently developed and proven in the practice software complexes, to carry out a comparative analysis of obtained results». Especially important this problem appears in the design of specific objects of various types and forms. Thus, the question of comparing the results of structure calculation by different computing complexes is relevant both in Russia and in other engineering developed countries.

Literature review

Despite the fact that the calculation computer programs and computing complexes have been used for a long time in the design of various types of structures, there is still not enough emphasis to the subject of comparison them with each other. At the moment, there are many publications describing principles of operation and design of structures in computing complexes, but in most cases each publication devoted to any one particular program, such as the publication of [2–7] devoted to work in the computing system Lira-Soft and the question of comparison with other complexes it does not rise there.

The SAP2000, developed by CSI America, for today is not such widespread in post-Soviet countries, as Lira, or SCAD. However, there are manuals devoted to the principles of work in this computing complex, for example, [8–9], which also do not address the question of comparing it with other computing complexes, perhaps precisely because of the low prevalence of SAP2000 in our countries.

There are only a few sources about the comparison of different program complexes on the basis of the results of calculations obtained in these programs. These publications include, for example, the article by A. V. Ioskevich [1], where the author compares the computing complexes SCAD Office and Lira-CAD on the example of calculation of 30-meter communication tower, or an article by G. S. Diaghilev [10], in which the author compares the computing complexes SCAD-Office and SAP2000 in the calculation of the roof of the Pulkovo Airport terminal. It is worth paying attention to the fact that A. V. Ioskevich [1] points out that the proposal of the Main State Expertise in Russia locally is not performed, and therefore there are a small number of papers in which the authors compared SCAD and Lira or other software complexes.

Purposes of investigation

The purpose of this work is to investigate the stress-strain state of metal structures on their numerical models and to compare the results of calculations of these models built using two independently developed software complexes. In this research, Lira-CAD version 9.6 and version 14.1 SAP2000 were taken to compare computing complexes.

«The program complex **LIRA** (PC LIRA) – is a multifunctional software complex for the calculation, investigation and design of structures of various purpose» [7]. Computing complex Lira-CAD has long been known to engineers mostly post-Soviet countries, performed well in the calculation of spatial systems, combined systems and other sophisticated models. It is relatively easy to use and has the usual Russian interface.

SAP2000 – a versatile integrated complex for the design of structures using FEM, developed by Computer and Structures, Inc. in California, USA. In Europe, for example in Spain, as well as in the United States and Canada SAP2000 for more than 10 years is widely used for solving a wide range of engineering problems, analysis of plane and spatial structures, bridges, etc.

On the territory of post-Soviet countries, including Russia, the SAP2000 computing complex is not so much widespread, despite of its simplicity and comparable with domestic programs possibilities. However, there are examples of using the program SAP2000 in Russia also, for example, the St. Petersburg State Polytechnic University included the study of SAP2000 in the training course for masters, and M. K. Savovich and D. V. Kamentsev from the Yugra State University published a manual [8], which also indicates the beginning of the implementation of SAP2000 in Russia. Labor market analysis showed that the specialists, owning SAP2000 are demanded in Russia, particularly in St. Petersburg design institutes.

Therefore, computing complex SAP2000 was chosen as the investigated program on a par with Lira-CAD, due to its low study, but the demand among practicing engineers.

A comparative study of structures

At the initial stage of comparison of programs a template design has been chosen as an object: steel vertical strut of height H = 40 m with rigidly fixed in the basis. Such strut was used for comparison the results of calculation in programs when working with a simple systems. In both programs the strut was modeled as a vertical rod, divided into 8 sections of 5 m each. In Lira-CAD system a finite elements type 10 – universal were used, because in SAP2000 a finite element type cannot be selected, and all the elements are universal default.

The appearance of strut models in Lira-CAD and SAP2000 is shown in Fig. 1.

Strut model has been considered as spatial with model feature № 5, in which the main unknowns are: the linear displacements of joints along the axes X, Y, Z, and rotations of joints around these axes also.

The calculation of strut model was held for horizontal dynamic load of 1 kN to obtain parameters of the stress-strain state of structure at its uploading by rhythmic dynamic load in both programs and further comparison of these parameters. The static load of its own weight (for deducing masses) and unit dynamic load were applied to strut.

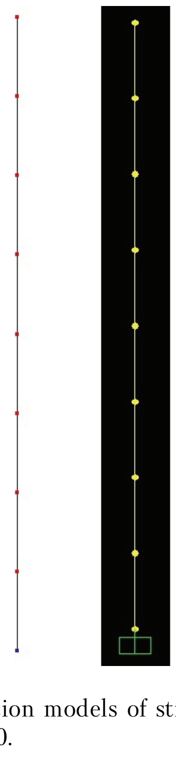


Figure 1. Calculation models of strut: left – in Lira; right – in SAP2000.

As a unit dynamic load to the strut in the top joint in the direction of the X-axis a sinusoidal load with the following parameters was applied:

Amplitude – A = 1 kN.

Frequency – 1.255 rad (2 complete cycles of 5 sec. each).

The duration of the function – 10 seconds.

Integration time – 10 seconds (100 steps of 0.1 seconds).

The mass of the system has been converted from a static own weight loading; the extra masses were not applied.

After the dynamic analysis of this system in time parameters of the stress-strain state of struts with different cross-section were obtained. In further analysis of the struts from all obtained parameters the horizontal displacements of the top joint of the system along the X-axis and the bending moment relative to the Y-axis at the base of the strut, as the most indicative for cantilever-clamped in the base system, were considered and compared. The maximum values of these parameters and the corresponding time values for different types of stiffening of strut are shown in Table 1.

For the calculation were used three types of stiffness of strut: Double T-beams HE 300B of EU 53-62, round tube 660.0×7.1 according to DIN 2458 and square tube TS 16×16×⅜ of ASTM A500 with a cross-section area of 149.00, 145.60 and 149.03 cm^2 respectively.

The graphs of the variation of displacements of the upper joint of system in time for the different cross-sections of the strut are shown on Fig. 2.

Analyzing obtained graphs of displacements it can be noted that Lira-CAD is more sensitive in calculation on dynamic loads, since it captures the specific moments of change of displacements. For example, on the graph Lira-CAD for round tube at the end of the second and the fourth wave is clearly visible horizontal platform on which the displacements remains unchanged over time. On the graph SAP2000 these places smoothed and clearly not distinguished that indicates a lower sensitivity of calculation algorithm and, as a consequence, the accuracy of the calculations.

In the second stage of programs comparison for investigation more complicated structure from metal elements was chosen: freestanding sectional steel communication tower height H = 180.0 m. According to a constructive solution the tower is a tetrahedral space truss, divided by height into 2

Table 1. The maximum values of parameters of the stress-strain state of strut

Parameter	Cross-section	Parameter values at corresponding time points – t, seconds							
		Lira-CAD				SAP2000			
		max +	t, s	max –	t, s	max +	t, s	max –	t, s
Displacement of upper joint along X-axis, mm	HE 300B	2 330.00	9.3	–1 869.00	6.9	1 848.00	9.4	–1 559.00	7.0
	∅660.0×7.1	215.80	3.3	–237.90	6.6	203.30	3.4	–218.80	1.7
	TS 16×16×⅜	779.40	4.1	–855.00	6.2	703.20	4.2	–751.00	6.3
Bending moment at the base relative to Y-axis, kNm	HE 300B	260.80	9.3	–207.30	7.0	198.70	9.4	–167.70	7.1
	∅660.0×7.1	70.49	3.2	–76.48	6.6	62.91	3.4	–68.71	1.7
	TS 16×16×⅜	130.76	4.1	–143.70	6.2	113.30	4.2	–120.60	6.3

main parts: from the level 0.0 m (ground level) to the level 155.0 m – trunk and from level 155.0 m to level 180.0 m – latticed pillar (Fig. 3).

The pillar is a grid structure in the form of a prismatic square rod with a cross lattice and the width of 1 750 mm. The latticed pillar is divided into spatial sections connected to each other with bolts.

The trunk is designed as grid in the form of three truncated pyramids, arranged one on another. The square basements of the pyramids has the following dimensions: at height 0 m – 31.000 mm; at height 32 m – 22.525 mm; at height 64 m – 12.250 mm; at height 155 m – 1.750 mm. Thus, the chords of the tower by height have 3 fractures (tilting relative to the vertical). The trunk of the tower also has a cross grid plus horizontal spacers for greater stability of chords.

Over the entire height of the tower inside it trunk and pillar horizontal diaphragms in the form of diamond-shaped bracings for the greater stability of tower during torsional effects are mounted.

Chords, braces, spacers and elements of horizontal diaphragms of tower made of tubular section. The dimensions of the cross-sections of elements are reduced from the bottom of the tower to the top of it in order to save material and reduce the own weight of tower.

Modeling of this tower in the Lira-CAD and SAP2000 was performed using the universal rod finite elements (type 10). Model feature just as in the first step of calculation was accepted № 5 – spatial system (6 degrees of freedom at the joint).

Fixing of tower in support joints – hinged, that limiting displacements of joints in all directions as well as rotation about the X-axis. Chords at the junction of the sections connected to each other rigidly, thereby forming a single hard chord over the entire height of the tower. Junction of lattice elements and horizontal bracings – hinged. Junction of horizontal spacers to chord – rigid.

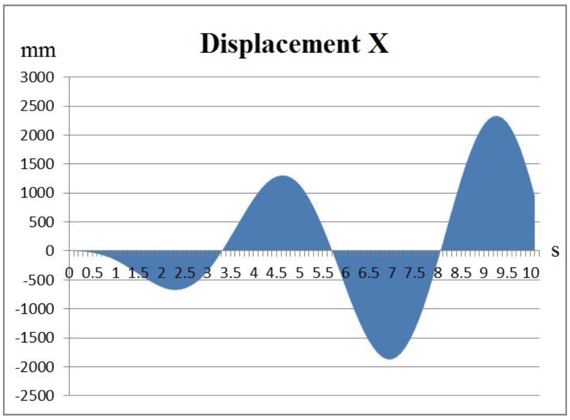
In modeling for the elements of the tower the following dimensions were applied: chords – ∅325×25, ∅245×18, ∅219×12, ∅168×11; bracings – ∅325×8, ∅219×8, ∅168×6, ∅89×5, ∅73×9, ∅60×6, ∅50×5; horizontal spacers – ∅325×8, ∅219×8, ∅168×6, ∅146×5, ∅89×5; horizontal diaphragms – ∅168×6, ∅89×5. All cross sections were taken in accordance with state standards GOST 10706-91 [11].

General view of the model of investigated tower in environments Lira-CAD and SAP2000 is shown in Fig. 3.

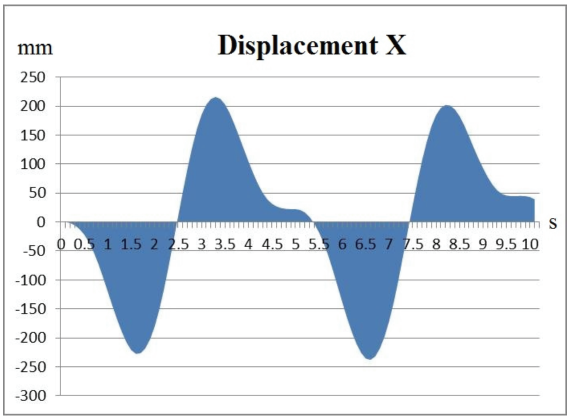
The process of creating a design scheme, the creation of loadings, dynamic loads in computing complexes Lira-CAD is generally similar to SAP2000. In addition, you can import the design scheme from the computing complex SAP2000 to Lira-CAD and conversely using the built-in tools that facilitates the work of an engineer in the comparative calculation.

Just like the strut, tower was loaded by its own weight and a dynamic sinusoidal unit load in X-axis direction that applied in the upper joints 1 and 2 of the tower. Scheme of application of dynamic forces can be seen in Fig. 4.

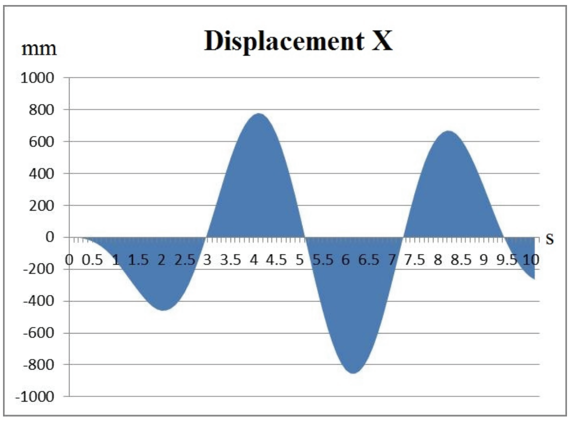
a) Double-T HE 300B



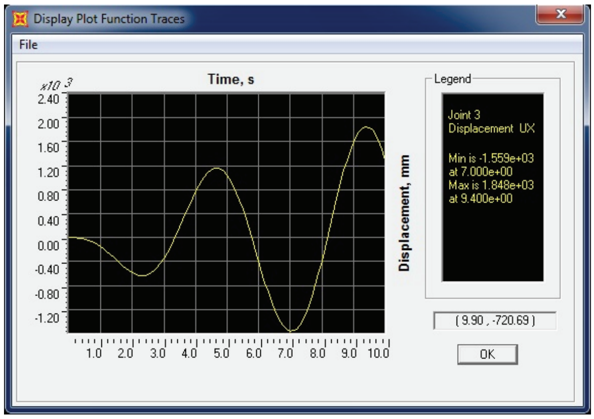
b) Round tube 660.0×7.1



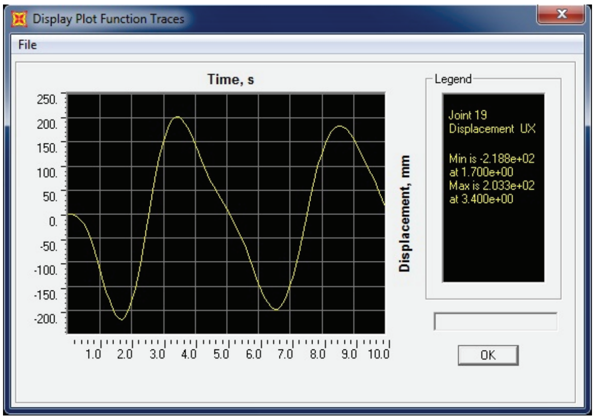
c) Square tube TS 16×16×3⁄8



d) Double-T HE 300B



e) Round tube 660.0×7.1



f) Square tube TS 16×16×3⁄8

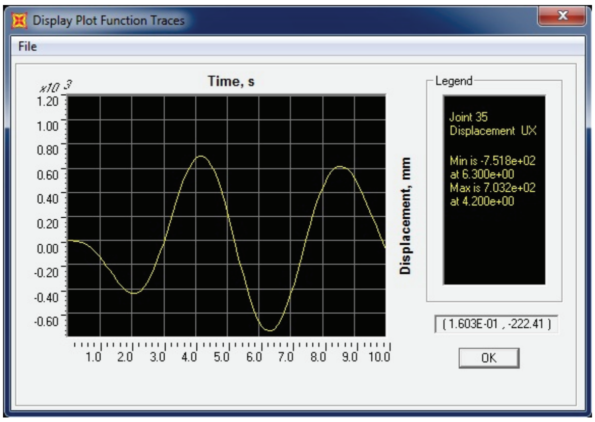


Figure 2. Graphs of the variation of horizontal displacements of upper joint of model along X-axis: a, b, c – graphs of Lira-CAD; d, e, f – graphs of SAP2000.

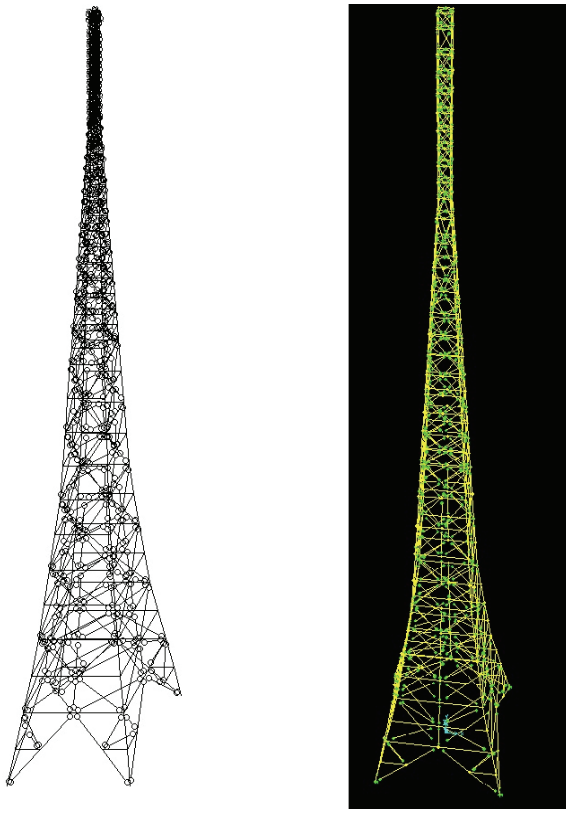


Figure 3. Calculation models of tower: left – in Lira-CAD; right – in SAP2000.

The parameters of the dynamic load are as follows: Amplitude A = 1 kN; Frequency – 1.255 rad (2 complete cycles of sine for 10 seconds); Duration of the function – 10 seconds; Integration time – 10 seconds (100 steps of 0.1 seconds).

Masses of system have been converted from uploading own weight.

As a result of the dynamic analysis the maximum values of displacements of four upper joints of the tower, as well as the maximum and minimum values of the longitudinal effort in the support sections of the four chords of the tower (the numbering of chords similar to the numbering of the upper joints, see Fig. 4) are obtained. The results are shown in Table 2.

A graphs of the time variation of displacements for Joint 1 are shown below (Fig. 5).

Analyzing these graphs it can be noted that, as in the case with struts on the graph of computing complex Lira-CAD at each wave of changing of displacements there are small jumps at the beginning or at the end, but on the graph of SAP2000 these jumps are not observed except small horizontal area on the first wave, which confirms the conclusion that the accuracy of dynamic calculations in SAP2000 is lower than in Lira-CAD.

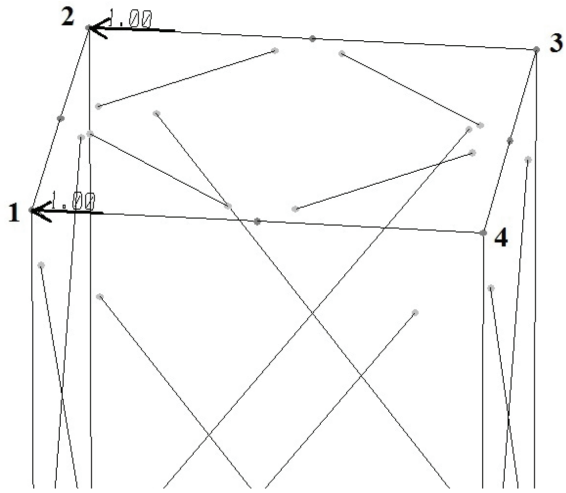


Figure 4. Places of application and directions of dynamic unit efforts.

Conclusions

1. The creation of calculation model is more convenient organized in Lira-CAD, as it allows to compose the scheme on the principle «item by item» from scratch, set joints and elements by the coordinates, but in SAP2000 has no possibility to create models «from scratch», it can offer only to select the initial scheme of several preloaded template schemes with a little number of customizable option types (dimensions, size of spans, floors, etc.) and its subsequent. However, Lira-CAD and SAP2000 have the ability to import a design model from the third-party software, including AutoCAD, as well as the ability to exchange data between these two programs directly. In the SAP2000 easier to work with design model in the 3-D, motion of model is smoother and clearer than in the Lira-CAD. Another advantage of SAP2000 is multi windows, the ability to work with different views of the same scheme in several windows at the same time. The drawbacks of SAP2000 include the lack

Table 2. Maximum and minimum values of parameters of the stress-strain state of tower

Parameter	Place of obtaining	Parameter values at corresponding time points – t, seconds							
		Lira-CAD				SAP2000			
		max +	t, s	max –	t, s	max +	t, s	max –	t, s
Displacement of upper joints along X-axis, mm	Joint 1	14.35	9.0	–14.67	6.0	12.31	3.8	–12.62	1.0
	Joint 2	14.41	9.0	–14.61	6.0	12.31	3.8	–12.62	1.0
	Joint 3	14.40	9.0	–14.60	6.0	12.31	3.8	–12.62	1.0
	Joint 4	14.34	9.0	–14.67	6.0	12.31	3.8	–12.62	1.0
		max	t, s	min	t, s	max	t, s	min	t, s
Longitudinal effort N in support section of chords, kN	Chord 1	–408.92	0.9	–389.29	4.0	–404.92	0.9	–392.62	3.9
	Chord 2	–408.93	0.9	–389.28	4.0	–404.90	0.9	–392.63	3.9
	Chord 3	–408.94	4.0	–389.31	0.9	–404.55	3.9	–392.26	0.9
	Chord 4	–408.95	4.0	–389.29	0.9	–404.54	3.9	–392.27	0.9

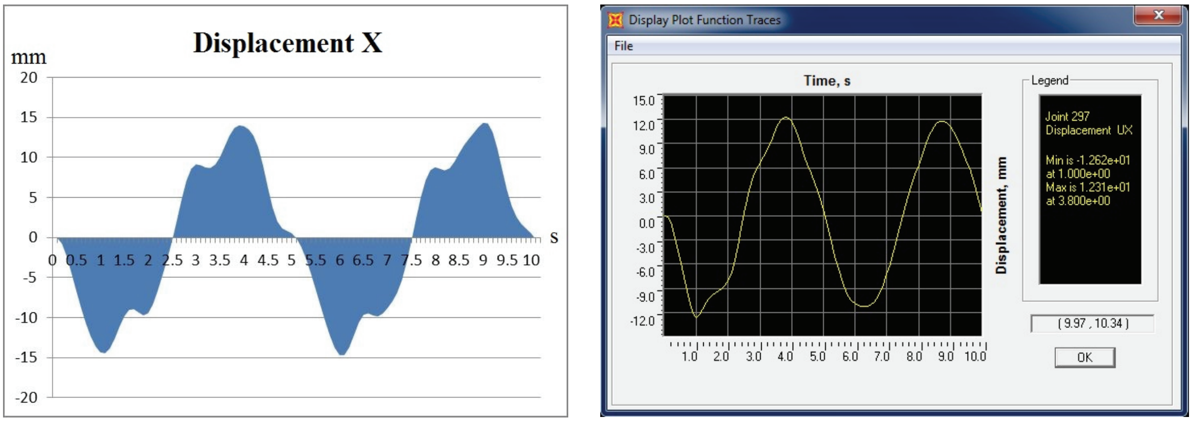


Figure 5. Graphs of variation of horizontal displacements of Joint 1 along X-axis: left – results of Lira-CAD; right – results of SAP2000

of finite element library; all the elements of design model are universal default.

2. Obtained results of dynamic calculations in the computing complexes Lira-CAD and SAP2000 in most cases have more than 10 % discrepancy, which indicates of their insufficient comparability within the investigated structure. This insufficient may be due to several reasons, which can be, for example, various tolerances, coefficients and accepted calculation hypotheses in the calculation formulas. However, the present and comparable values having discrepancy less than 10 %, such as displacements in tube strut (Table 1) and longitudinal efforts in the chords of the tower (Table 2). At the same time, although the results of calculations of two programs for the most part are not comparable, certain regularities are observed: Lira gives values of maximum displacements and efforts greater than SAP2000, but the time points at which these values are observed in Lira almost always on 0.1 second less than in SAP2000.
3. From the analysis of presented in paper graphs of displacements (Fig. 2 and 5), we can conclude that in dynamic calculations computing complex Lira-CAD is more sensitive than SAP2000, and therefore has a higher accuracy of the calculation.
4. Taking into account all the advantages and disadvantages of computing complex SAP2000 we can say that this program is a great tool to work with is not very complicated structures,

due to the absence of the library of finite elements, but rather quick work of 3-D module. Most likely, the main reason of low prevalence of complex SAP2000 in post-Soviet countries is the lack of Russian language interface.

5. For deeper comparison of the results of calculations using Lira-CAD and SAP2000 it is necessary to carry out comparative calculations on real objects, whereby it is possible to define rational scope of these programs.

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Тимошко Андрій Олександрович – аспірант кафедри технології і організації будівництва Донбаської національної академії будівництва і архітектури. Наукові інтереси: напружено-деформований стан висотних будівель з металевих конструкцій з урахуванням монтажних впливів.

Югов Анатолій Михайлович – доктор технічних наук, професор; завідувач кафедри технології і організації будівництва Донбаської національної академії будівництва і архітектури. Член Української асоціації з металевих конструкцій, Член Міжнародної асоціації просторових конструкцій, Член Української спілки з неруйнівного контролю та технічної діагностики. Наукові інтереси: експлуатаційна надійність будівельних металевих конструкцій, технічна діагностика будівельних конструкцій, технологія і організація монтажа металевих конструкцій, робота металевих конструкцій с урахуванням монтажних станів.

Тимошко Андрей Александрович – аспирант кафедры технологии и организации строительства Донбасской национальной академии строительства и архитектуры. Научные интересы: напряженно-деформированное состояние высотных зданий из металлических конструкций с учетом монтажных воздействий.

Югов Анатолий Михайлович – доктор технических наук, профессор; заведующий кафедрой технологии и организации строительства Донбасской национальной академии строительства и архитектуры. Член Украинской ассоциации по металлическим конструкциям, Член Международной ассоциации по пространственным конструкциям, Член Украинского общества по неразрушающему контролю и технической диагностике. Научные интересы: эксплуатационная надежность строительных металлических конструкций, техническая диагностика строительных конструкций, технология и организация монтажа металлических конструкций, работа металлических конструкций с учетом монтажных состояний.

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