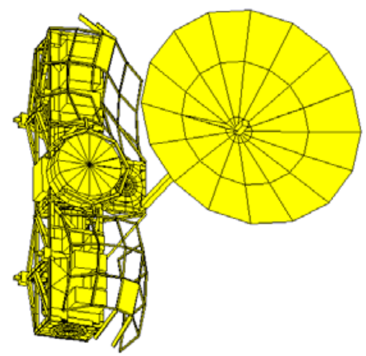
CONTEMPORARY PROBLEMS OF NUMERICAL MODELING OF UNIQUE STRUCTURES, BUILDINGS AND COMPLEXES



Prof. *Alexander M. Belostotsky & Co*

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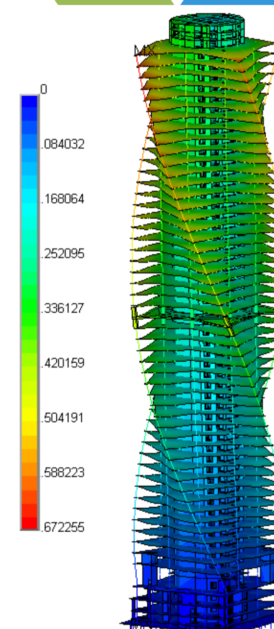
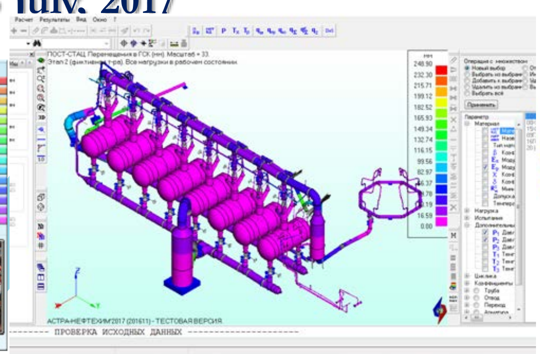
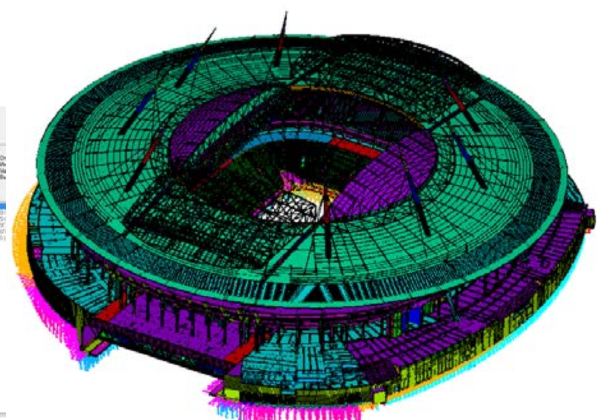


Dubna, MMCP'2017, 03 July, 2017





DIRECTIONS OF ACTIVITY

Contemporary problems of mathematical modellng of unique structures, buildings and complexes

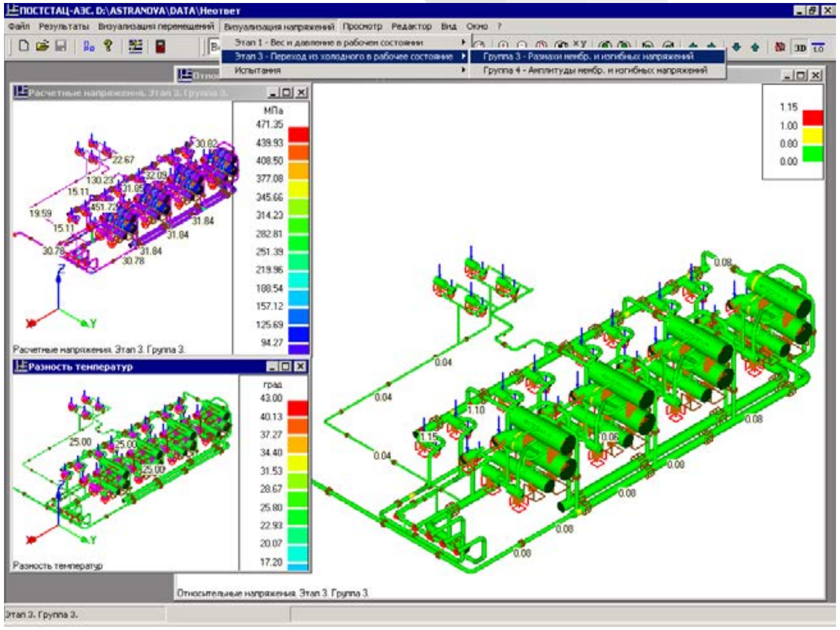
- Modelling of interaction of buildings and structures with a soil/foundation with allowance for real properties, stage-by-stage construction and actual operation history;
- Structural analysis with allowance for physical, geometrical and other nonlinearities (plasticity of metal, creep and crack formation of reinforced concrete, nonlinear rheology of the foundation, large displacements, loss of stability, postbuckling behaviour, contact problems (friction separation, etc.));
- Structural analysis with allowance for structural and technological specificity (structural (constructive) nonlinearity, genetic nonlinearity) of buildings and facilities (construction sequence, stage-by-stage construction, sensitivity of buildings and structures, assessment of the quality of the constructive solution from the position of the sensitivity of the stress-strain state to corresponding design deviations);
- Numerical modelling of wind flows and loads (average and pulsation components, loads on facade structures, pedestrian comfort, vortex resonance oscillations), experimental validations of wind load analysis.

DIRECTIONS OF ACTIVITY

Contemporary problems of mathematical modellng of unique structures, buildings and complexes

- Seismic analysis (with allowance for acceleration spectra (versions of the linear-spectral theory), accelerograms, platform models, wave effects);
- Progressive collapse analysis of buildings and facilities with allowance for real dynamic highly nonlinear effects of elastoviscoplasticity and large displacements;
- Development and refinement of methods and algorithms for solution of large-scale computational problems (direct and iterative solvers, superelement technology, adaptive schemes, parallelizing, etc.);
- Development of calibratable predictive mathematical and computer models as part of structural health monitoring systems at the stages of erection and operation of buildings and facilities;
- Application of algorithms of aerodynamics for modelling of snow sedimentations, explosion loads and distribution of hazardous emissions;
- Numerical modelling of three-dimensional nonstationary roblems of fire resistance;
- Solution of coupled problems of aerohydroelasticity

DIRECTIONS OF ACTIVITY



Development of proprietary software

Certification of software in the system of Gosatomnadzor - Rosatomnadzor and verification of software in the system of the Russian Academy of Architecture and Constrcution Sciences

Review of results of structural analysis with the use of verified software

- Review of results of structural analysis with the use of verified software;
- Qualification tests and certification of specialists dealing with computational structural analysis and corresponding experts reports;
- Verification of numerical methods and software used in design and structural analysis;
- Construction and technical expertise of buildings and facilities (including cases of local destruction)

DIRECTIONS OF ACTIVITY

Development and refinement of methods of structural analysis

- Research and development of numerical methods of structural analysis (finite element method (FEM), boundary element method (BEM), variation-difference method (VDM), meshless method, finite volume method (FVM) etc);
- Research and development of semianalytical methods of structural analysis (discrete-continual methods).

Training of specialists-users of software systems used for mathematical modelling of structures, buildings, facilities

- Training of specialists-users of universal software systems used for mathematical modelling of structures, buildings and facilities;
- Training of specialists-users of object-oriented software systems used for mathematical modelling of structures, buildings and facilities.

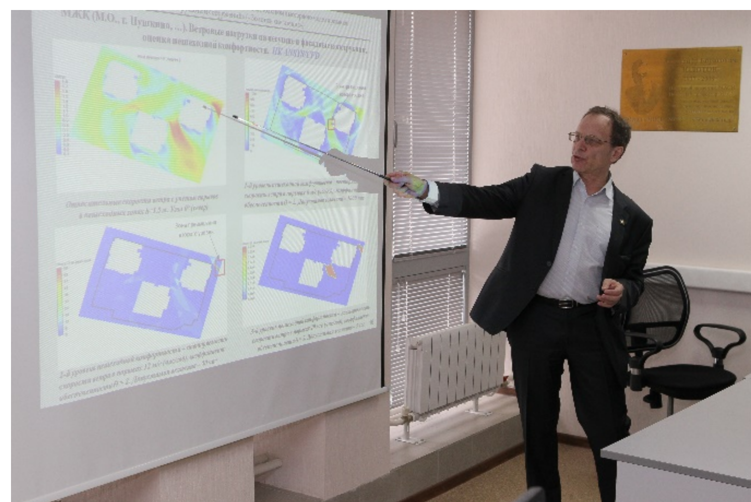
DIRECTIONS OF ACTIVITY

Solution of scientific and technical problems

- Multifactor structural analysis and structural health monitoring of buildings and facilities (including unique objects, development of expert reports and recommendations for optimization);
- Development of predictive mathematical and computer models as an “intellectual” basis and as part of structural health monitoring systems;
- Scientific collaboration with the Russian Academy of Architecture and Construction Sciences;
- Related objects and tasks (in particular, analysis of coupled systems “pipelines – equipment – structures").

Scientific and educational activity

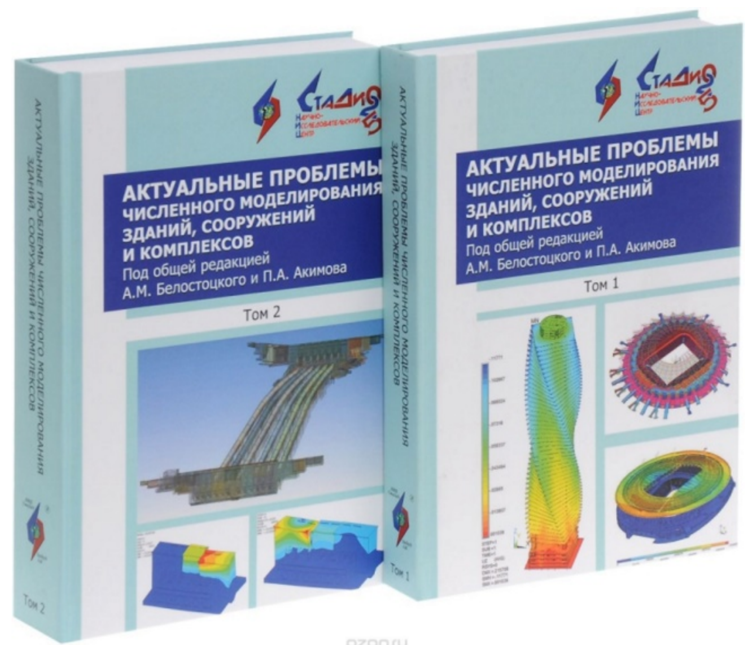
- Master of Science programs in the fields of “Applied Mathematics” and “Construction”;
- PhD programs in the fields of “Informatics and Computer Engineering” and “Engineering and technology of construction”.



DIRECTIONS OF ACTIVITY

Scientific and educational activity

- “Open lectures”, specialized training courses, seminars, counseling (including counseling in the preparation of graduate qualification works);
- Training of specialists within the programs of supplementary vocational education in the fields of large-span and high-rise buildings, underground structures, nuclear, thermal and hydroelectric power stations, pipeline systems for various purposes etc);
- Organization and development of scientific research & educational centers and laboratories in leading Russian universities;
- Organization and participation in Russian and international scientific events (conferences, symposiums, seminars, etc.);
- Preparation of textbooks, tutorials and monographs on topical problems of mathematical and computer simulation of the condition of buildings, structures and complexes.



Multilevel Superelement Modelling of Stress-Strain State of Three-Dimensional Combined Systems Under Static and Dynamic Loads

Finite element formulation

$$\varepsilon_{ij} = \varepsilon_{ij}^{e} + \varepsilon_{ij}^{\theta} + \varepsilon_{ij}^{vp}$$

$$[M]\{\ddot{u}(t)\} + [C]\{\dot{u}(t)\} + [K]\{u(t)\} = \{F(t)\} + \{R(u,\dot{u})\}$$

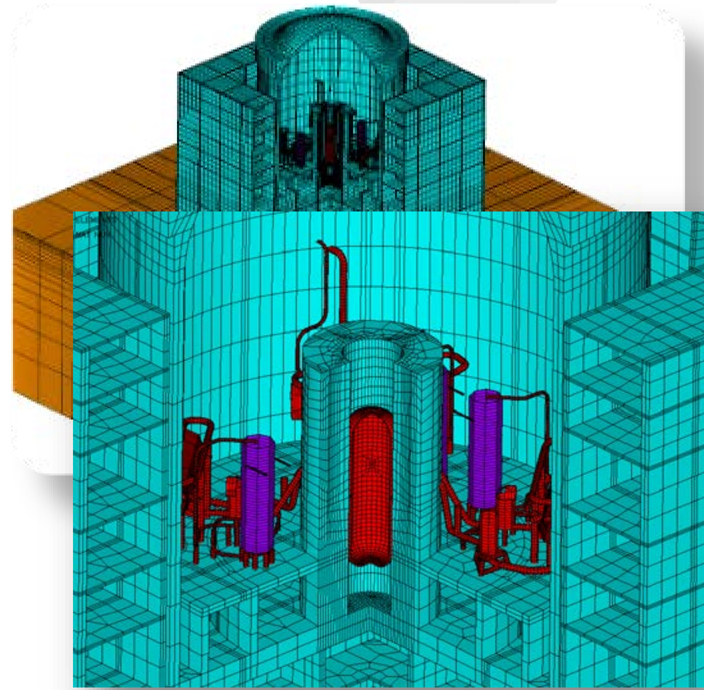
$$u(t_0) = u_0, \quad \dot{u}(t_0) = v_0, \quad u(t)\big|_s = u_s(t)$$

The superelement form of the decomposition of the stiffness matrix

$$\begin{bmatrix} K_{ii} & K_{ib} \\ K_{bi} & K_{bb} \end{bmatrix} = \begin{bmatrix} U_i^{\mathrm{T}} & 0 \\ R^{\mathrm{T}} & U_b^{\mathrm{T}} \end{bmatrix} \begin{bmatrix} D_i & 0 \\ 0 & D_b \end{bmatrix} \begin{bmatrix} U_i & R \\ 0 & U_b \end{bmatrix}$$

$$[R] = [D_i]^{-1}([U_i]^{\mathrm{T}})^{-1}[K_{ib}]$$

$$[U_b]^{\mathrm{T}}[D_b][U_b] = [K_{bb}] - [K_{bi}][K_{ii}]^{-1}[K_{ib}] = [\bar{K}]$$

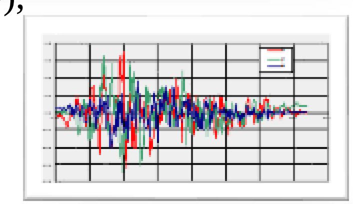


$$[\bar{M}]\{\ddot{u}_b\} + [\bar{C}]\{\dot{u}_b\} + [\bar{K}]\{u_b\} + \sum[G][\Omega]\int_0^t \mathrm{SIN}[\Omega(t-\tau)][G]^{\mathrm{T}}\{u_b(\tau)\}d\tau = \sum(\{\bar{F}(t)\} - [G][\Omega]^2\{q(t)\}),$$

$$\{u_b(0)\} = \{u_{0b}\}, \{\dot{u}_b(0)\} = \{v_{0b}\}$$

$$[\bar{M}] = [M_{bb}] - [M_{bi}][M_{ii}]^{-1}[M_{ib}] \qquad [\bar{K}] = [K_{bb}] - [K_{bi}][K_{ii}]^{-1}[K_{ib}]$$

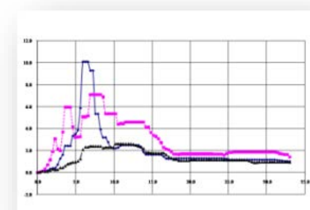
$$\{\bar{F}(t)\} = \{F_b(t)\} - [M_{bi}][M_{ii}]^{-1}\{F_i(t)\} \qquad [G] = [K_{bi}][\Phi][\Omega]^{-2} - [M_{bi}][\Phi]$$



$$\{q\} = \{q(t)\} = \mathrm{COS}[\Omega t][\Phi]^{\mathrm{T}}[M_{ii}]\{\bar{u}_{0i}\} + [\Omega]^{-1}\,\mathrm{SIN}[\Omega t][\Phi]^{\mathrm{T}}[M_{ii}]\{\bar{v}_{0i}\} +$$

$$+ [\Omega]^{-1}\,\mathrm{SIN}[\Omega t] * [\Phi]^{\mathrm{T}}\{F_i(t)\},$$

$$\{\bar{u}_{0i}\} = \{u_{0i}\} + [K_{ii}]^{-1}[K_{ib}]\{u_{0b}\} \qquad \{\bar{v}_{0i}\} = \{v_{0i}\} + [K_{ii}]^{-1}[K_{ib}]\{v_{0b}\}$$



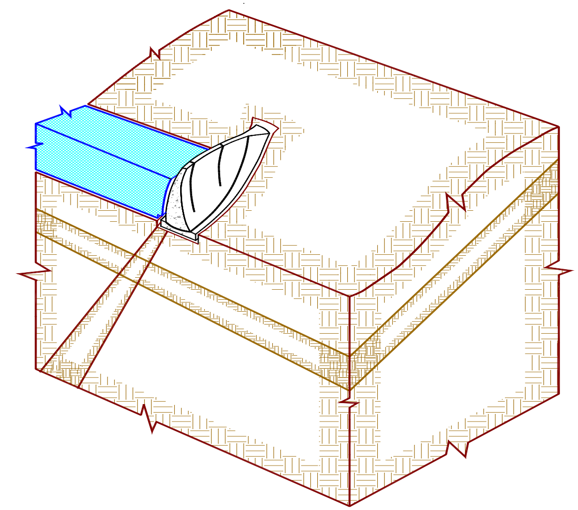
Three-Dimensional Dynamic Structural Analysis of System "Structure – Foundation – Reservoir"

Alternative models and algorithms provide adequate research of the coupled hydroelastic system and eliminate "parasite" computational properties of standard formulations

The formulation in mixed unknowns (Euler's approach)

$$\begin{cases}[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+[S]\{p\}=\{F\}, & V\in V_s\cup V_f\\ \rho_w[S]^{\mathrm{T}}\{\ddot{u}\}+[G]\{\ddot{p}\}+[C]_w\{\dot{p}\}+[H]\{p\}=\{q\}, & V\in V_w\end{cases}$$

$$s_{rt}=\iint n_k\, N_i\, N_j\, d\sigma;\ \sigma\in S_{sw}\cup S_{fw},\ r=3(i-1)+k;\ t=3m+j;\ i,j=1,\ \dots,m,\ k=1,2,3.$$



The formulation in displacements (the Lagrangian approach)

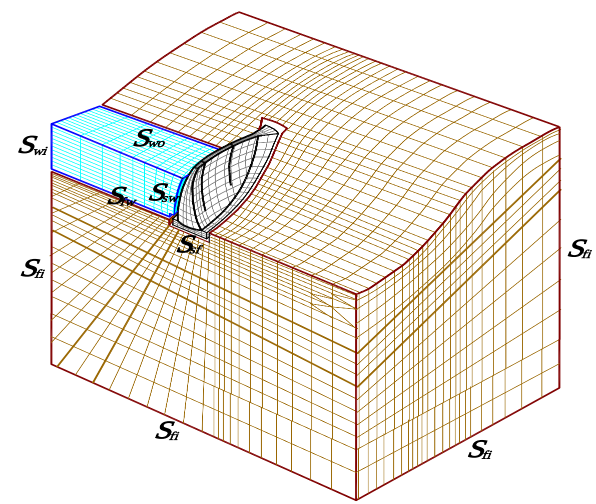
$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+[S]_{w0}\{u_3\}=\{F\}, V\in V_s\cup V_f\cup V_w$$

$$[S]_{w0}=\rho_w g\iint_{S_{w0}}[N]^T[N]ds$$ - *учет поверхностных гравитационных волн*

$$\{\varepsilon\}_w^T=\left[e,e_x,e_y,e_z\right],\quad e=\partial u_1/\partial x_1+\partial u_2/\partial x_2+\partial u_3/\partial x_3,\quad e_x=\left(\partial u_2/\partial x_3-\partial u_3/\partial x_2\right)/2,\dots$$

$$[D]_w=diag(K_w,C_{22},C_{33},C_{44}),\ C_{ii}=(100\div 10000)\,K_w$$

$$p=-\rho_w C_w\frac{1-\alpha_w}{1+\alpha_w}\dot{u}_n\Rightarrow[C]_{wi}=\rho_w C_w\frac{1-\alpha_w}{1+\alpha_w}\iint_{S_{wi}}[N]^T[N]ds, S\in S_{fw}$$



The scheme of the matrix of the apparent masses (incompressible fluid)

$$([M]+[M]_w)\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F\}, V\in V_s\cup V_f$$

$$[M]_w=\frac{1}{\rho_w}[S]^T[H]^{-1}[S],\quad S\in S_{sw}\cup S_{fw}$$

Allowance for Nonlinear Friction-Opening Effects in Joints, Macrocracks and at Contact Surfaces

Specially developed version of the superelement method leads to a significant saving of computational effort. For nonlinear problems solution is not computed in internal nodes, and the rate of convergence of the iterative processes at the last superelement level is higher than when using the same algorithms for solution of initial problems of large dimension

1. Reduction of the problem

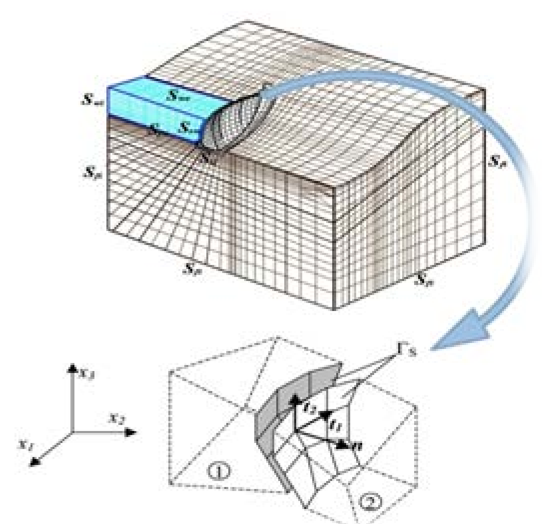
2. change of variables $w_t = \tilde{u}_2^t - \tilde{u}_1^t \qquad w_n = \tilde{u}_2^n - \tilde{u}_1^n$

$$\left[\begin{array}{cc|cc} \tilde{K}_{11}^{tt}+\tilde{K}_{12}^{tt}+\tilde{K}_{21}^{tt}+\tilde{K}_{22}^{tt} & \tilde{K}_{11}^{tn}+\tilde{K}_{12}^{tn}+\tilde{K}_{21}^{tn}+\tilde{K}_{22}^{tn} & \tilde{K}_{12}^{tt}+\tilde{K}_{22}^{tt} & \tilde{K}_{12}^{tn}+\tilde{K}_{22}^{tn} \\ \tilde{K}_{11}^{nt}+\tilde{K}_{12}^{nt}+\tilde{K}_{21}^{nt}+\tilde{K}_{22}^{nt} & \tilde{K}_{11}^{nn}+\tilde{K}_{12}^{nn}+\tilde{K}_{21}^{nn}+\tilde{K}_{22}^{nn} & \tilde{K}_{12}^{nt}+\tilde{K}_{22}^{nt} & \tilde{K}_{12}^{nn}+\tilde{K}_{22}^{nn} \\ \hline \tilde{K}_{21}^{tt}+\tilde{K}_{22}^{tt} & \tilde{K}_{21}^{tn}+\tilde{K}_{22}^{tn} & \tilde{K}_{22}^{tt} & \tilde{K}_{22}^{tn} \\ \tilde{K}_{21}^{nt}+\tilde{K}_{22}^{nt} & \tilde{K}_{21}^{nn}+\tilde{K}_{22}^{nn} & \tilde{K}_{22}^{nt} & \tilde{K}_{22}^{nn} \end{array}\right] \left\{\begin{array}{c} \tilde{u}_1^t \\ \tilde{u}_1^n \\ \hline w_t \\ w_n \end{array}\right\} = \left\{\begin{array}{c} \tilde{f}_1^t+\tilde{f}_2^t \\ \tilde{f}_1^n+\tilde{f}_2^n \\ \hline \tilde{f}_2^t \\ \tilde{f}_2^n \end{array}\right\}$$

$$\begin{bmatrix} K_{tt} & K_{tn} \\ K_{nt} & K_{nn} \end{bmatrix} \begin{Bmatrix} w_t \\ w_n \end{Bmatrix} = \begin{Bmatrix} f_t \\ f_n \end{Bmatrix}$$

3. Solution of problems with conditions of one-way contact

$$\begin{cases} \tilde{K}_n w_n = \tilde{f}_n + s_n \\ w_n \ge 0 \\ s_n \le 0 \\ w_n \cdot s_n = 0 \end{cases} \qquad \tilde{K}_n = K_{nn} - K_{nt} K_{tt}^{-1} K_{tn} \qquad \tilde{f}_n = f_n - K_{nt} K_{tt}^{-1} f_t$$



4. Solution of problems with conditions of one-way contact and friction

Material Models with Allowance for Physical Nonlinearity

Algorithm of nonlinear three-dimensional analysis based on the "energy" rheological model of the soil and developed schemes of the finite element method

Problem is solved at each step the "external" iterations of the system of linear equations of equilibrium of finite element model with immense number of unknowns (specific to real three-dimensional models) with the use of effective version of the incomplete factorization method – preconditioned conjugate gradient method gradients.

Step-by-step (incremental) loading

"External" iteration process

$$[K(\sigma)] = [K]^L + \sum_e [k(\sigma)]^e \qquad [k(\sigma)]^e = \int\int\int_{v^e} [B']^T [D'(\sigma)][B'] dV$$

$$D^{/}_{ii}(\sigma) = \lambda(\sigma) + 2\mu(\sigma); \quad D^{/}_{ij}(\sigma) = \lambda(\sigma); \quad D^{/}_{kk}(\sigma) = \mu(\sigma), \quad i, j = 1,2,3; k = 4,5,6$$

Loading: $dU = \int S_{ij} d\varepsilon_{ij} + \int \sigma de \geq 0$ **Unloading:** $dU < 0$

$$\mu(\sigma) = \sigma^{1-n}\left(\frac{E_0 f(\nu) e^{B(\bar{K}-1)}}{n} + G_0 \bar{K}\left(1 - e^{B(\bar{K}-1)(t-\tau)^{\eta}}\right)\right); \qquad \mu(\sigma) \equiv \mu_P = G_{0P};$$

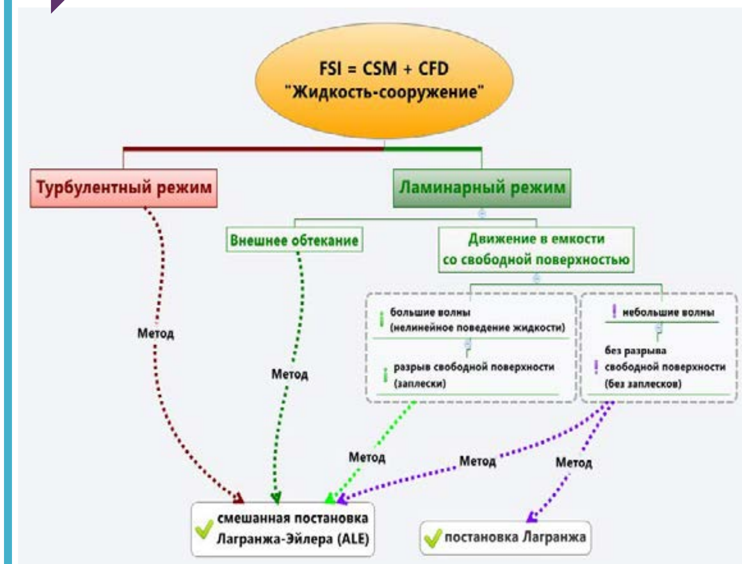
$$\lambda(\sigma) = \frac{E_0 \sigma^{1-n}}{n(1 - e^{-\beta(t-\tau)^{1-\xi}})^n} - \frac{2}{3}\mu(\sigma) \qquad \lambda(\sigma) \equiv \lambda_p = E_{0P} - \frac{2}{3}\mu_P$$

"Internal" iterative process for each stress point

Adaptive Method of Numerical Simulation of Three-Dimensional Dynamic Problems of Structural Aerohydroelasticity

1. Subject of research

2. Classification



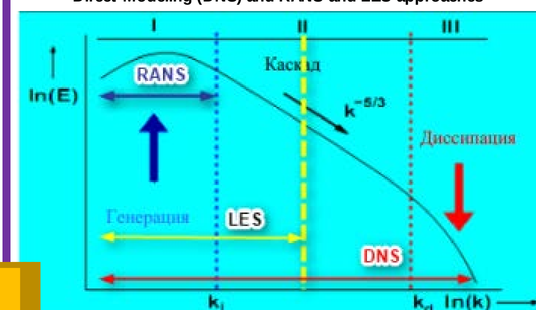
3. Effective mathematical models and numerical methods

Mathematical Formulation

- ***Lagrangian*** formulation
- ***Eulerian*** formulation
- ***Arbitrary Lagrangian Eulerian (ALE)*** formulation

Turbulence modelling

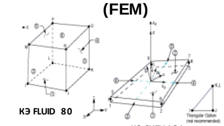
Permissible scales of vortices
Direct Modeling (DNS) and RANS and LES approaches



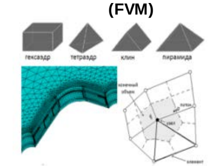
Energy spectrum of turbulence under the condition of big Reynolds number, Re

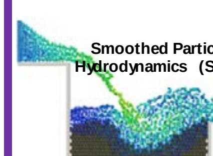
Numerical approximation

Finite element method (FEM)



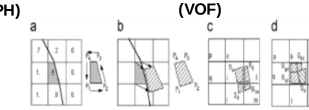
Finite volume method (FVM)





Smoothed Particle Hydrodynamics (SPH)

Volume of fluid method (VOF)



4. Aerohydroelastic analysis

- ✓ Parameters of deformable meshes
- ✓ Parameters of stability and convergence of solution at contact boundary
- ✓ Proprietary software systems

1. Direct method

Sample (Lagrangian formulation):

- Fluid ➡ *Lagrangian formulation* ➡ volume finite elements
- Tank ➡ *Lagrangian formulation* ➡ shell finite elements

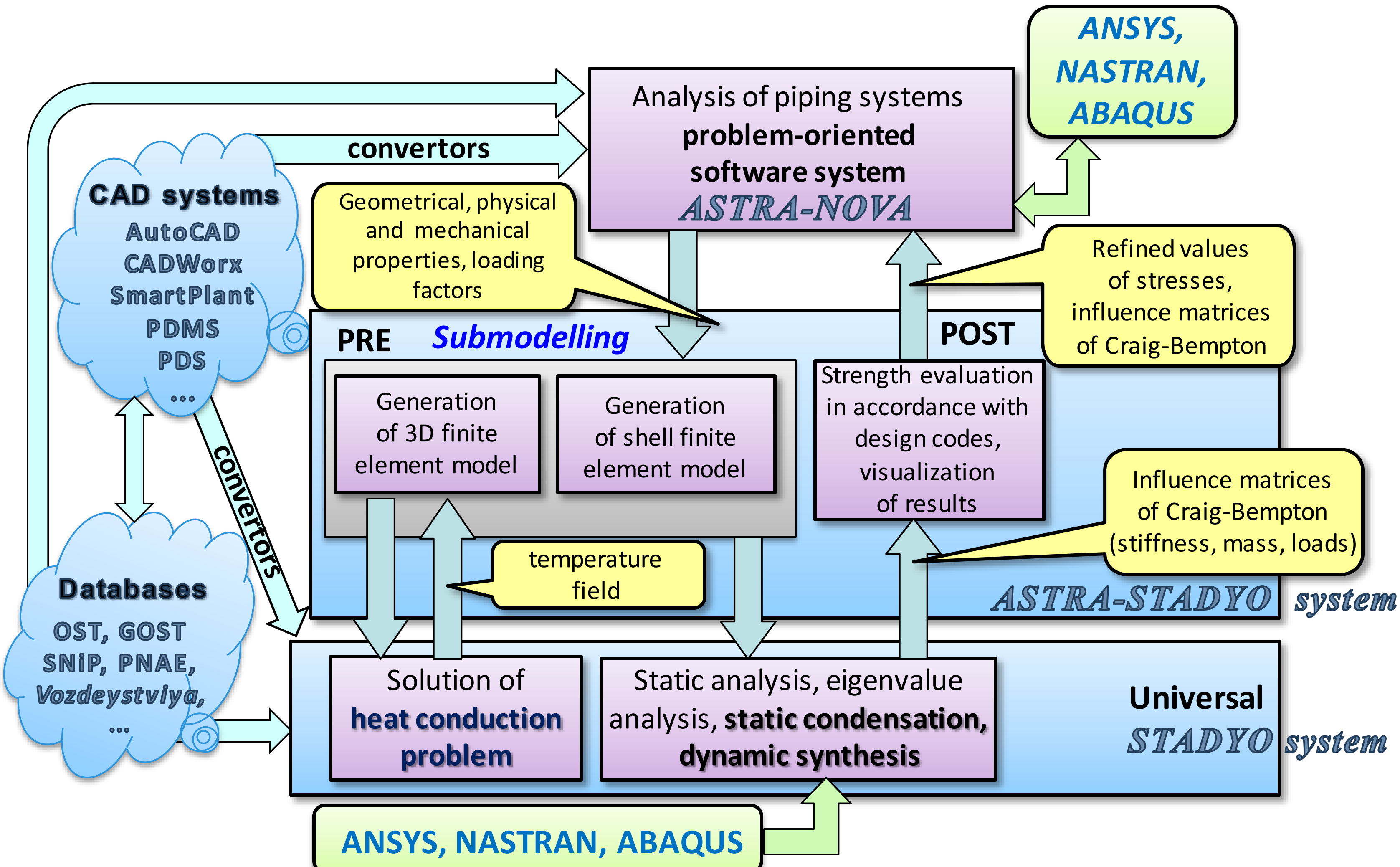
2. Load transmission method

Sample (mixed formulation) :

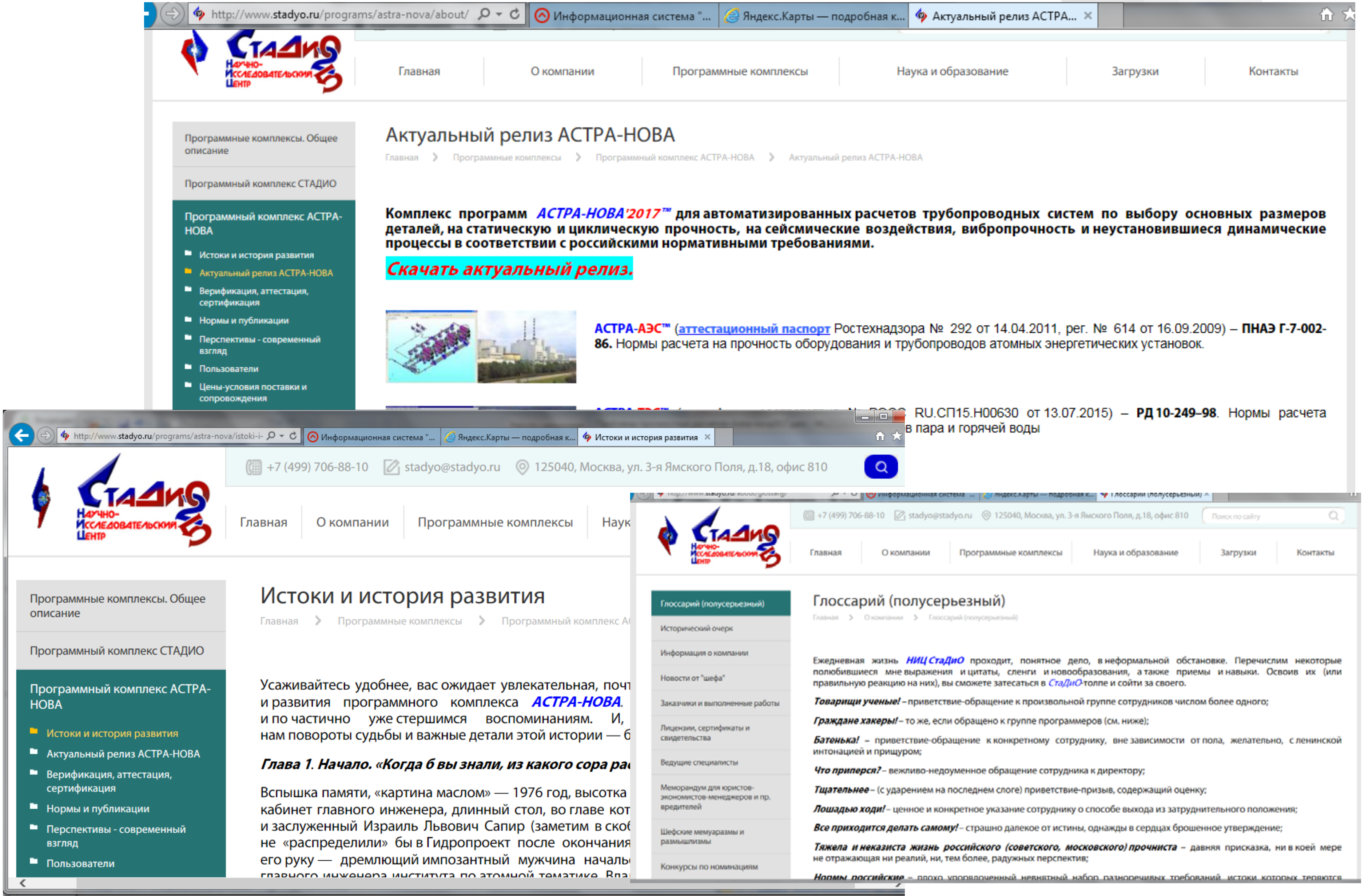
- Fluid ➡ *Eulerian formulation* ➡ ***Multiphase flow + Free surface*** ➡ volume finite elements and finite volumes
- Tank ➡ *Lagrangian formulation* ➡ shell finite elements

Development, Adaptation and Verification of software systems

Proprietary software systems based on superelement method (substructuring method): universal (*STADYO*) and object-oriented (*ASTRA-NOVA*)



Development, Adaptation and Verification of software systems



Modules of ASTRA-NOVA'2017

Module	Russian Rules
ASTRA-AES	ПНАЭ Г-7-002-86
ASTRA-TES	РД 10-249-98
ASTRA-NEFTEKHIM	РТМ 38.001-94, ГОСТ 32388-2013*
ASTRA-TEPLOSET	РД 10-400-01, ГОСТ Р 55596-2013*
ASTRA-MAGISTR	СНиП 2.05.06-85, СП 36.13330.2012, ГОСТ Р 55989-2014, ГОСТ Р 55990-2014
ASTRA-SVD	РД РТМ 26-01-44-78, ГОСТ Р 55600-2013

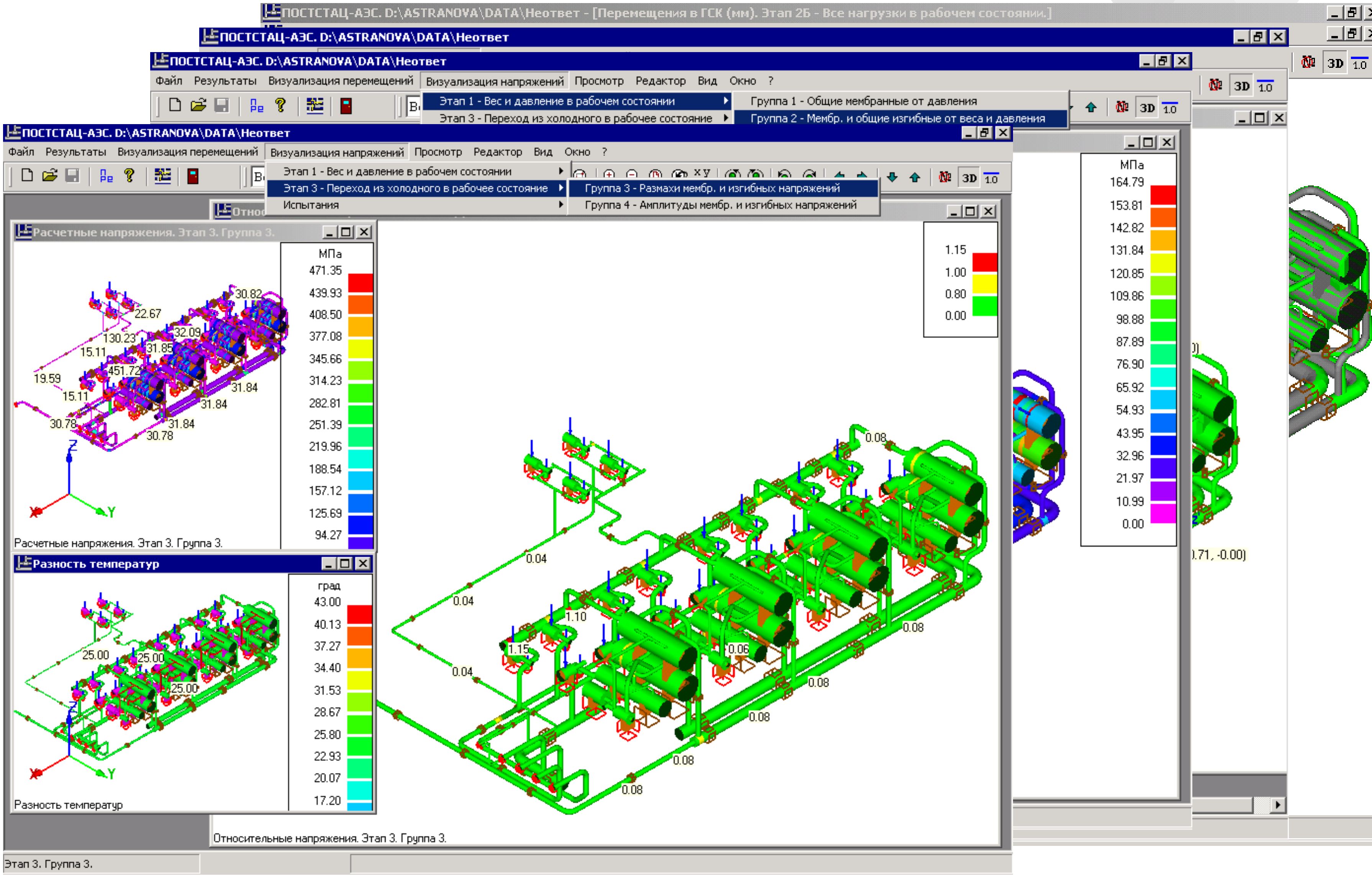
*** - May, 2017**

Development, Adaptation and Verification of software systems

Modules of ASTRA-NOVA'2017

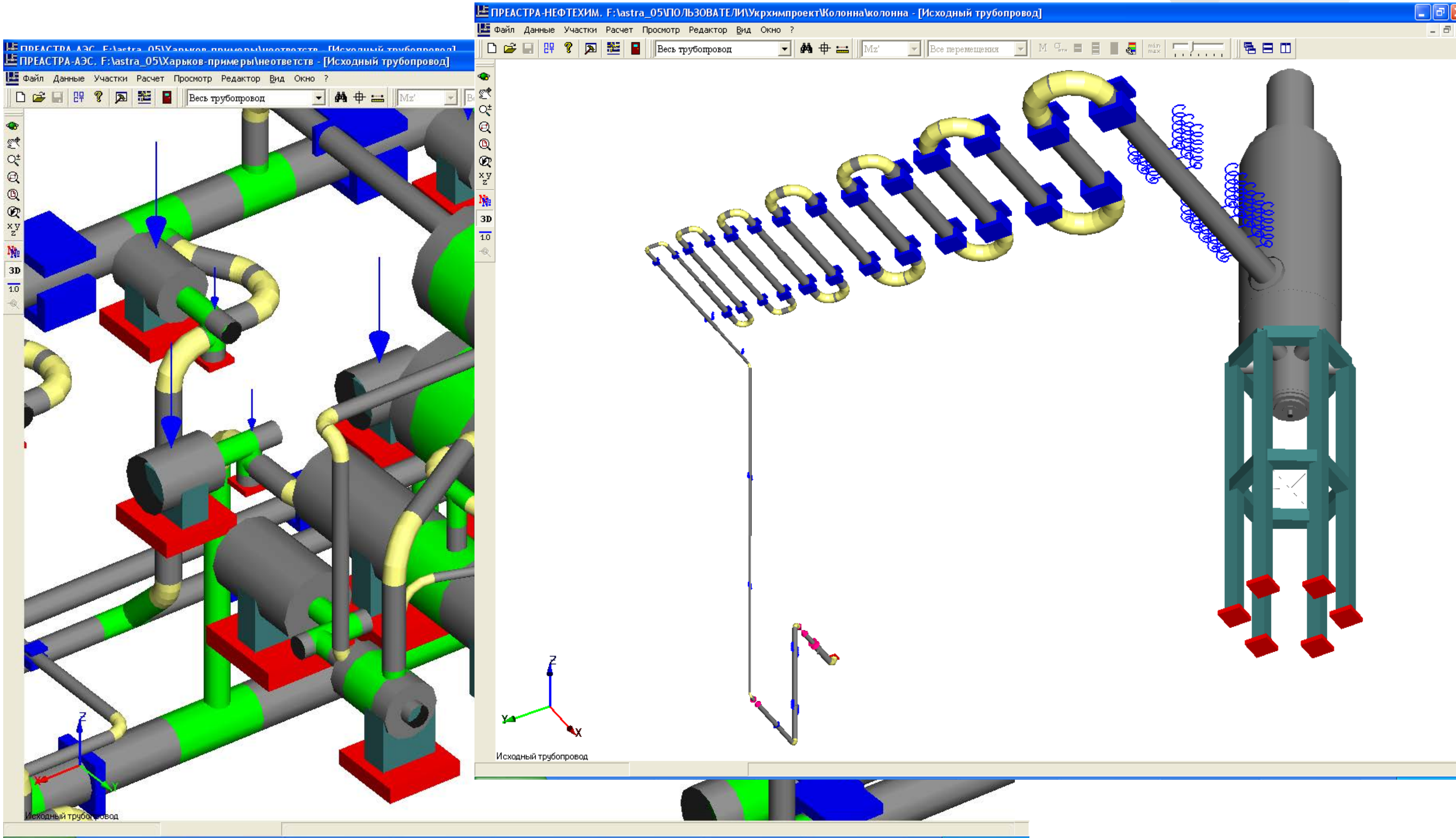
ASTRA-DETAL	Basic dimensions of pipeline details
PRE-ASTRA	Preprocessor
ASTRA-STAT	Static analysis, cyclical parameters
POST-ASTRA	Postprocessor
ASTRA-FORM	Modal analysis
ASTRA-SEISM	Seismic analysis
ASTRA-VIBR	Vibration analysis
ASTRA-DYN	Dynamic analysis
ASTRA-STADYO	thermal state, stress-strain state, strength analysis, elastoplastic analysis (refined FEA)

Development, Adaptation and Verification of software systems



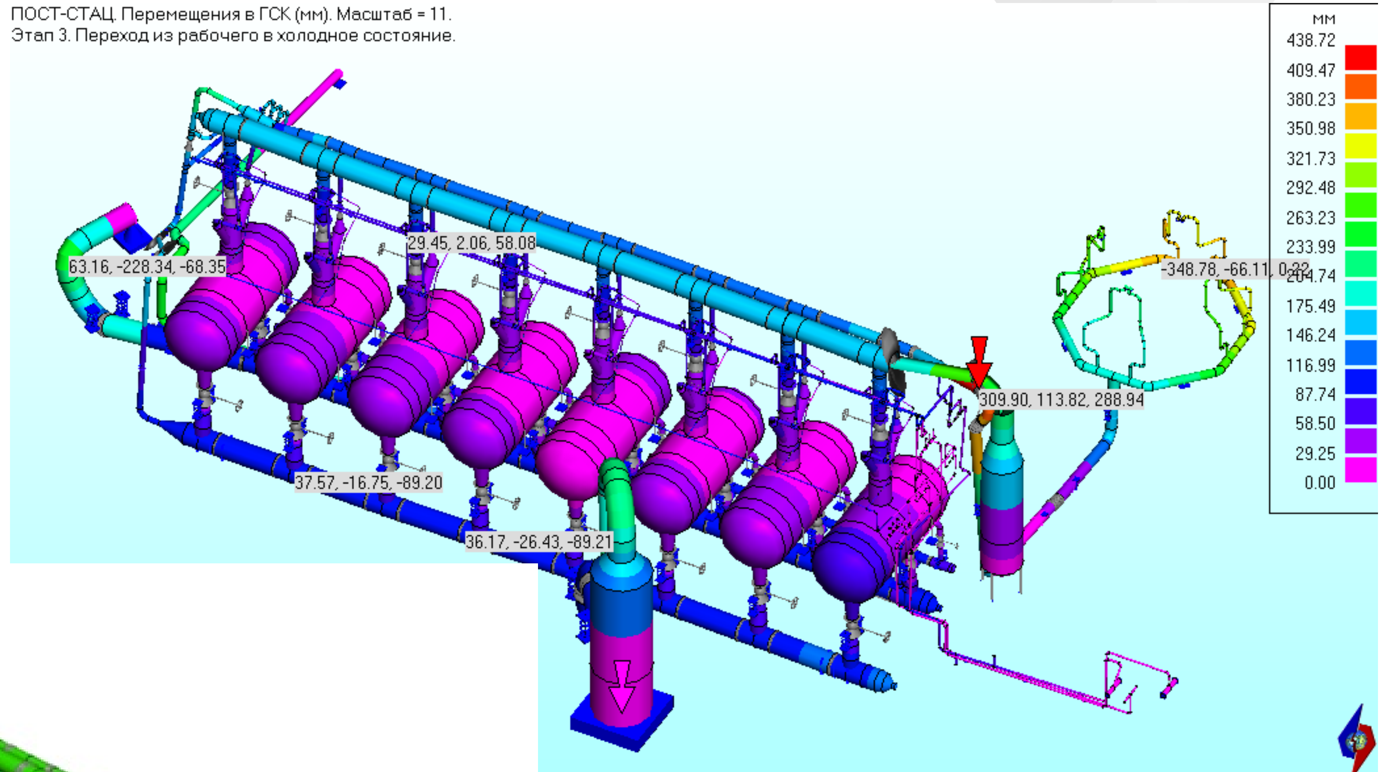
Results of computational analysis (***ASTRA-STAT***)

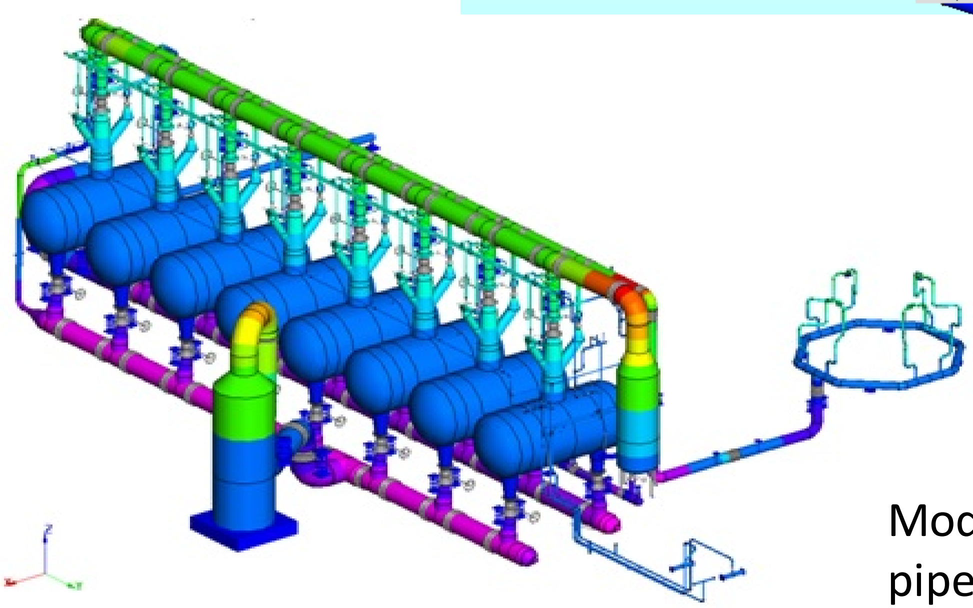
Development, Adaptation and Verification of software systems



Modeling of complex supporting structures and equipment in the system

Development, Adaptation and Verification of software systems



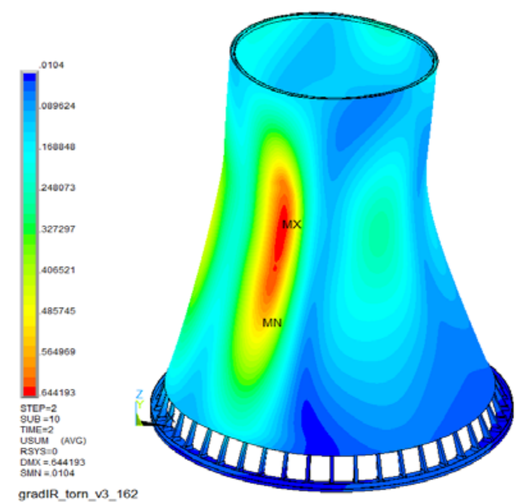


Modeling&analysis of complex supporting pipeline-equipment system

EXPERIENCE IN THEORETICAL AND PRACTICAL COMPUTATIONAL ANALYSIS (40-YEAR HISTORY)

Three-dimensional thermal and stress-strain state, stability, strength and reliability of pipelines, technological, electrotechnical and lifting-transport equipment, machines and mechanisms, structures, coupled systems “equipment – pipelines”, “foundation – overground structure”, “foundation – subground structure” of buildings, facilities and complexes, with allowance for design and actual load combinations (including temperature loads, static loads, wind loads, operational load (vibrations), special dynamic loads (seismic, shock-wave, emergency and other)) :

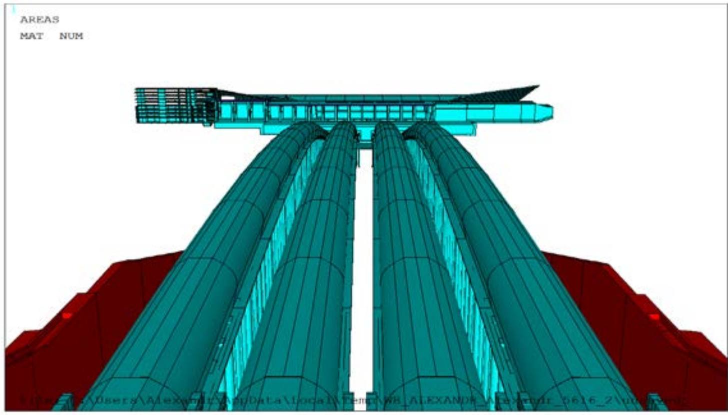
- ***Reactor compartments, engine rooms, generator halls, turbine buildings, reserve diesel power plants and cooling towers of nuclear power plants (NPP) and waste storages*** *(Armenian, Kursk, Smolensk, Chernobyl, Leningrad, Ignalina, Bilibino, Novovoronezh, Kola, Balakovo, Volgodonsk, Kalinin, Zaporozhye, Beloyarsk, Lovisa, Kozloduy, Belene, Paksh, Temelin, Stendal, Kudankulam, Tianwan, Bushehr, new generation NPP (AS-NP 500, AS-NP 1000, NP 2006, NPP with WWER-TOI, etc.));*



EXPERIENCE IN THEORETICAL AND PRACTICAL COMPUTATIONAL ANALYSIS (40-YEAR HISTORY)

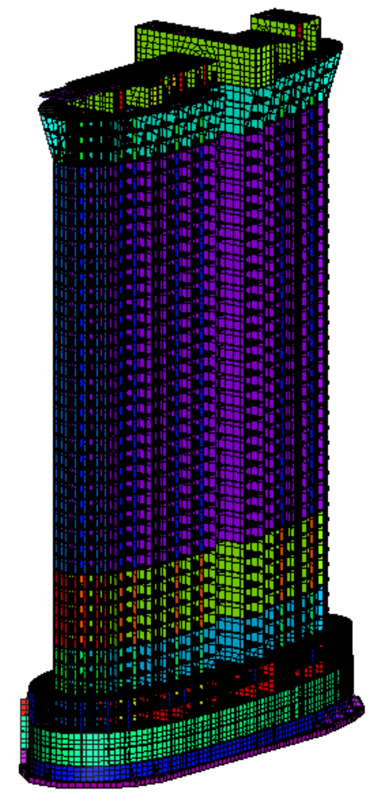
- **Arched, gravity and earth dams, underground structures and buildings of hydroelectric power stations** (Sayano-Shushenskaya, Krasnoyarskaya, Bratskaya, Boguchanskaya, Zeyskaya, Bureyskaya, Vilyuyskaya, Katun, Chirkeiskaya, Volzhskaya, Kamskaya, Inguri, Khudoni, Namakhvani, Kurpsai, Nurek, Rogun, Plyavinskaya , Gekhi, Hoabin, Kapanda, Teri, Tang-E-Duk, etc.), **hydroelectric pumped storage power stations** (Zagorskaya), **tidal hydroelectric stations, coast protection structures, other hydraulic strctures**;

- **Unique and typical buildings and structures of civil engineering** (roof of Grand Sports Arena of Luzhniki Olympic Complex (Moscow), the monument to the 300th anniversary of the Russian fleet (Moscow), underground parking of shopping and entertainment mall “Manezhnaya Square” (Moscow), sports and fitness complex “Aquadrom”, ice stadium “Megasport” located on Khodynka (Moscow), sports complex “Moskvich” (Moscow), indoor swimming pool of the “Iskra” sanatorium (Sochi), ice palace “Bolshoi” (Sochi), bobsleigh track “Sanki” and the ski complex “Gorki” (Sochi, Winter Olympic Games – 2014), football stadiums of the World Cup 2018 (“Zenit” (Saint-Petersburg), “Spartak” (Moscow), stadiums located at Volgograd, Samara, Nizhny Novgorod and Rostov-on-Don), …



EXPERIENCE IN THEORETICAL AND PRACTICAL COMPUTATIONAL ANALYSIS (40-YEAR HISTORY)

- **Unique and typical buildings and structures of civil engineering** (multifunctional high-rise complexes (including Moscow International Business Center "Moscow-City", Poklonnaya (Moscow), Profsoyuznaya (Moscow), Leningradskaya (Moscow), building located at Volgograd, Omsk, Vladivostok, Krasnodar, Kiev, Astana), multi-block shopping and entertainment centers, multi-storey panel block sections and monolithic buildings, schools and polyclinics, banners with allowance for initial tension of ropes, wind loads and other factors);



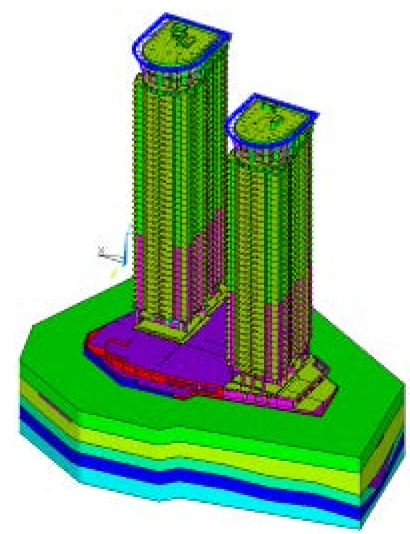
- **Overground and underground pipelines of heating systems, main oil and gas pipelines, petrochemical and gas pipelines and equipment** (analysis of "Sakhalin – Khabarovsk – Vladivostok" gas pipeline system is among the last comprehensive and "breakthrough" researches);
- **Wind power plants of various types and capacities**;
- **Floating structures and platforms for the offshore extraction of oil and gas**;
- **Various bio- and nanostructures** (for example, double linear and closed DNA (deoxyribonucleic acid) helices).

EXPERIENCE IN THEORETICAL AND PRACTICAL COMPUTATIONAL ANALYSIS (40-YEAR HISTORY)

- **Complex mechanical engineering structures, machines and mechanisms** including aerospace systems, transport, shipbuilding, power engineering, ferrous and non-ferrous metallurgy, consumer electronics, etc. (analysis of stress-strain state, dynamic response and strength of the coupled system “Science power platform – drive unit – solar batteries” and subsystems of the International Space Station (ISS) “Alpha” at the stages of launch and orbital activity;

Complex, including record-sized (up to 200 million unknowns) three-dimensional stationary and non-stationary problems of building aerodynamics dealing with computing of average and pulsating components of wind loads, wind loads on facade and enclosing structures, pedestrian comfort of numerous unique objects:

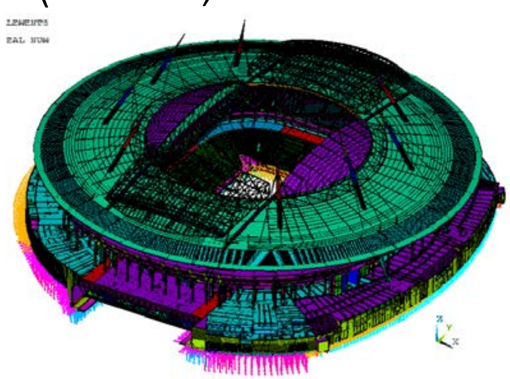
- **High-rise buildings, structures and complexes** (Moscow International Business Center “Moscow-City”, “Gazoil City” (Moscow), “Zodiac” (Moscow), “Sky Fort” (Moscow), “Dirigible” (Moscow), “Rublevsky Lights” (Moscow), “Aquamarine” (Vladivostok), group of buildings of National Research Moscow State University of Civil Engineering, Ostankino TV Tower in Moscow, buildings located at Saint-Petersburg, Kiev, Astana, etc.);

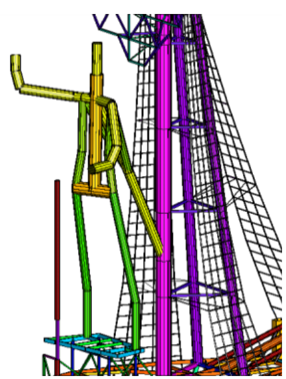


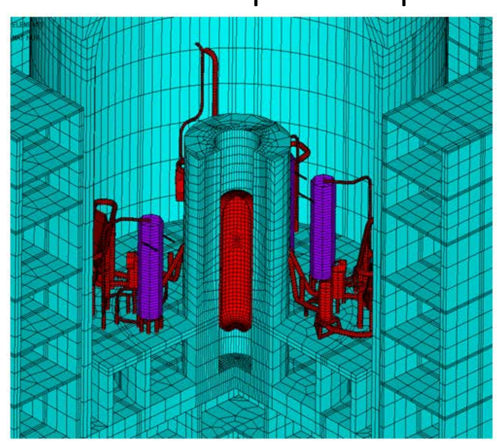
EXPERIENCE IN THEORETICAL AND PRACTICAL COMPUTATIONAL ANALYSIS (40-YEAR HISTORY)

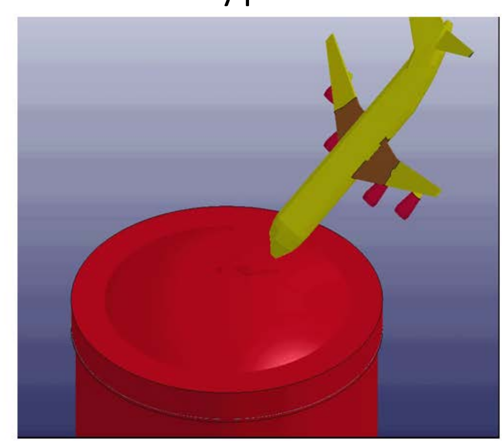
- **Large-span buildings and structures** (stadiums “Moskvich” (Moscow), “Zenit” (Saint-Petersburg), railway station in Adler, a ski jumping complex of Winter Olympic Games – 2014, etc.);
- **Monuments** (monument on Poklonnaya Hill (Moscow), monuments “Conquerors of the Cosmos” and “Worker and Collective Farm Girl” at the Exhibition of Economic Achievements (VDNKh, Moscow), etc.);
- **Complex of basic structures of nuclear power plant with WWER** (reactor compartments, engine rooms, evaporative cooling towers, etc.) with allowance for extreme (hurricane) wind and tornado.

Besides, contemporary problems of refined numerical modeling and aircraft crashes are considered for the basic structures of nuclear power plants of various types (WWER, RBMK and BN).









SOFTWARE SYSTEMS FOR ANALYSIS OF LOADS AND EFFECTS, STRENGTH AND STABILITY OF STRUCTURES, BUILDINGS AND COMPLEXES

Universal software systems	Object-oriented software systems	Research noncommercial software systems	Software for solution of particular problems	CAD systems and convertors
ANSYS ANSYS Mechanical ANSYS/CFD ANSYS/LS-DYNA ANSYS/AUTODYN	ANSYS/CivilFEM	DIANA	PLAXIS	AutoCAD
SIMULIA ABAQUS	Robot Structure	STADYO	FlowVision	PDS
MSC NASTRAN	ASTRA-NOVA	UZOR	OM SNiP “Zhelezobeton”	SmartPlan
	MicroFE		Zemlya	
	LIRA-SAPR			
	SCAD			
	LIRA-10.*			
	MIDAS Civil MIDAS GTS			

SOFTWARE SYSTEMS FOR ANALYSIS OF LOADS AND EFFECTS, STRENGTH AND STABILITY OF STRUCTURES, BUILDINGS AND COMPLEXES

РОССИЙСКАЯ АКАДЕМИЯ АРХИТЕКТУРЫ И СТРОИТЕЛЬНЫХ НАУК

Научный совет «Программные средства в строительстве и архитектуре»

СВИДЕТЕЛЬСТВО

№ 02/ANSYS/2009

о верификации программного средства, применяемого для решения задач теплопроводности и фильтрации, определения статического и динамического напряженно-деформированного состояния конструкций, зданий и сооружений

Программное средство: **ANSYS Mechanical** – универсальный программный комплекс для решения задач теплопроводности и фильтрации, определения статического, температурного и динамического напряженно-деформированного состояния пространственных конструкций, зданий и сооружений с учетом эффектов физической, геометрической, структурной и генетической нелинейностей на основе метода конечных элементов

Разработчик: **ANSYS, Inc** (США)

Заявители: **ЗАО “ЕМТ Р”, ЗАО НИЦ СтаДиО, ООО “ГК Техстрой”, ГОУ ВПО МГСУ** (Россия)

Авторы верификационного отчета: **ЗАО НИЦ СтаДиО, ГОУ ВПО МГСУ** (Россия)

Дата включения в реестр верифицированных программных средств: **10 июля 2009 года**

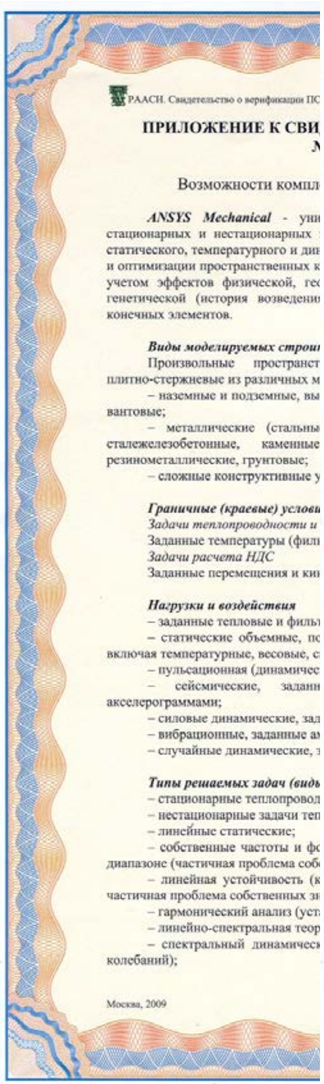
Срок действия свидетельства: до **10 июля 2019 года**

Перечень верифицированных возможностей программного средства **ANSYS Mechanical** изложен в Приложении (на 4 стр.), являющемся неотъемлемой частью настоящего Свидетельства, и в верификационном отчете (4 тома на 1200 стр.)

Вице-Президент	В.И. Травуш
Академик-Секретарь	Н.И. Карпенко
Председатель Научного Совета	В.Н. Сидоров

Verification of **ANSYS Mechanical** in the system of the Russian Academy of Architecture and Construction Sciences

SOFTWARE SYSTEMS FOR ANALYSIS OF LOADS AND EFFECTS, STRENGTH AND STABILITY OF STRUCTURES, BUILDINGS AND COMPLEXES



РААСН. Свидетельство о верификации ПС

ПРИЛОЖЕНИЕ К СВИ

Возможности компл

ANSYS Mechanical - уни стационарных и нестационарных статического, температурного и ди и оптимизации пространственных к учетом эффектов физической, ге генетической (история возведени конечных элементов.

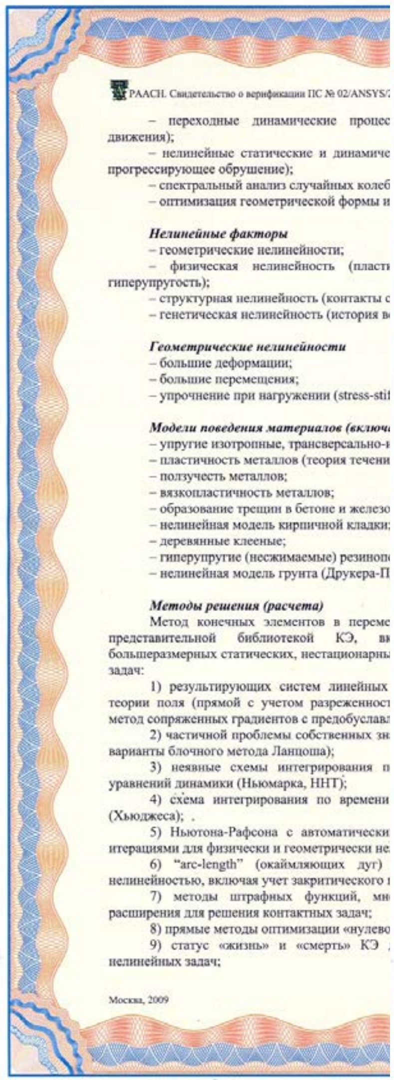
Виды моделируемых строи
Произвольные пространст плитно-стержневые из различных м
– наземные и подземные, вы вантовые;
– металлические (стальны сталежелезобетонные, каменные резинометаллические, грунтовые;
– сложные конструктивные у

Граничные (краевые) услови
Задачи теплопроводности и
Заданные температуры (фил
Задачи расчета НДС
Заданные перемещения и ки

Нагрузки и воздействия
– заданные тепловые и филь
– статические объемные, п включая температурные, весовые, с
– пульсационная (динамичес
– сейсмические, задан акселерограммами;
– силовые динамические, за
– вибрационные, заданные а
– случайные динамические,

Типы решаемых задач (виды
– стационарные теплопровод
– нестационарные задачи те
– линейные статические;
– собственные частоты и ф диапазоне (частичная проблема соб
– линейная устойчивость (частичная проблема собственных з
– гармонический анализ (уст
– линейно-спектральная теор
– спектральный динамическ колебаний);

Москва, 2009



РААСН. Свидетельство о верификации ПС № 02/ANSYS/

– переходные динамические процес движения);
– нелинейные статические и динамиче прогрессирующее обрушение);
– спектральный анализ случайных колеб
– оптимизация геометрической формы и

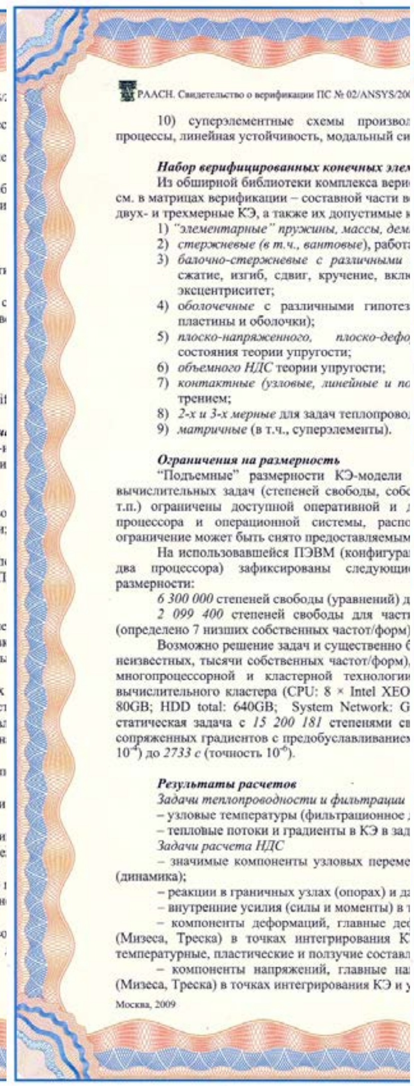
Нелинейные факторы
– геометрические нелинейности;
– физическая нелинейность (пласти гиперупругость);
– структурная нелинейность (контакты с
– генетическая нелинейность (история в

Геометрические нелинейности
– большие деформации;
– большие перемещения;
– упрочнение при нагружении (stress-sti

Модели поведения материалов (включ
– упругие изотропные, трансверсально-
– пластичность металлов (теория течени
– ползучесть металлов;
– вязкопластичность металлов;
– образование трещин в бетоне и железо
– нелинейная модель кирпичной кладки;
– деревянные клееные;
– гиперупругие (несжимаемые) резинопо
– нелинейная модель грунта (Друкера-П

Методы решения (расчета)
Метод конечных элементов в переме представительной библиотекой КЭ, в большеразмерных статических, нестационарны задач:
1) результирующих систем линейных теории поля (прямой с учетом разреженност метод сопряженных градиентов с предобуславл
2) частичной проблемы собственных зн варианты блочного метода Ланцоша);
3) неявные схемы интегрирования п уравнений динамики (Ньюмарка, ННТ);
4) схема интегрирования по времени (Хьюджеса);
5) Ньютона-Рафсона с автоматическ итерациями для физически и геометрически не
6) "arc-length" (окаймляющих дуг) нелинейностью, включая учет закритического
7) методы штрафных функций, м расширения для решения контактных задач;
8) прямые методы оптимизации «нулево
9) статус «жизнь» и «смерть» КЭ нелинейных задач;

Москва, 2009



РААСН. Свидетельство о верификации ПС № 02/ANSYS/20

10) суперэлементные схемы произво процессы, линейная устойчивость, модальный си

Набор верифицированных конечных элем
Из обширной библиотеки комплекса вери см. в матрицах верификации – составной части в двух- и трехмерные КЭ, а также их допустимые
1) *"элементарные" пружины, массы, дем*
2) *стержневые (в т.ч., вантовые)*, работ
3) *балочно-стержневые с различными* сжатие, изгиб, сдвиг, кручение, вкл эксцентриситет;
4) *оболочечные* с различными гипоте пластины и оболочки);
5) *плоско-напряженного, плоско-дефо* состояния теории упругости;
6) *объемного НДС* теории упругости;
7) *контактные (узловые, линейные и п* трением;
8) *2-х и 3-х мерные* для задач теплопрово
9) *матричные* (в т.ч., суперэлементы).

Ограничения на размерность
"Подъемные" размерности КЭ-модели вычислительных задач (степеней свободы, соб т.п.) ограничены доступной оперативной и процессора и операционной системы, распо ограничение может быть снято предоставляемым
На использовавшейся ПЭВМ (конфигура два процессора) зафиксированы следующи размерности:
6 300 000 степеней свободы (уравнений) д
2 099 400 степеней свободы для част (определено 7 низших собственных частот/форм)
Возможно решение задач и существенно неизвестных, тысячи собственных частот/форм), многопроцессорной и кластерной технологи вычислительного кластера (CPU: 8 × Intel XEO 80GB; HDD total: 640GB; System Network: G статическая задача с *15 200 181* степенями св сопряженных градиентов с предобуславливание 10^{-4}) до *2733 с* (точность 10^{-6}).

Результаты расчетов
Задачи теплопроводности и фильтрации
– узловые температуры (фильтрационное
– тепловые потоки и градиенты в КЭ в за
Задачи расчета НДС
– значимые компоненты узловых переме (динамика);
– реакции в граничных узлах (опорах) и д
– внутренние усилия (силы и моменты) в
– компоненты деформаций, главные де (Мизеса, Треска) в точках интегрирования К температурные, пластические и ползучие состав
– компоненты напряжений, главные на (Мизеса, Треска) в точках интегрирования КЭ и

Москва, 2009

РААСН. Свидетельство о верификации ПС № 02/ANSYS/2009. Приложение

– собственные частоты и формы колебаний (требуемое количество или в заданном частотном диапазоне);
– критические нагрузки и формы потери устойчивости;
– амплитуды перемещений, усилий и напряжений для заданных частот виброворздействия (АЧХ);
– «статус» контакта, длина/площадь, нагрузки на контактных поверхностях, линиях и узлах;
– коэффициенты интенсивности напряжений и J-интегралы (механика разрушения);
– оптимизированные параметры конструкции (форма, сечения и др.);
– картины образования трещин в элементах бетона и железобетона;
– невязки по силам и перемещениям (нелинейные задачи).

Точность численных результатов
Зависит от класса (типа) задач, "качества" построенной КЭ-модели (сетки) и, в особенности для нелинейных задач, от выбранного метода (схемы) решения. Подробно – в матрицах верификации для решенных задач.
Для линейных задач при соблюдении известных и документированных требований к моделированию точность определения основных параметров поля, статического и динамического НДС превышает 1%. Для задач с «глубокой» нелинейностью и(или) при сложных моделях физической нелинейности расхождение с «эталонными» результатами может достигать 15-20%.

Возможность включения собственных конечных элементов, моделей поведения материалов, решателей и т.п.
Реализована с помощью прикомпилируемых пользовательских подпрограмм.

Сведения о базах данных (библиотеках констант), используемых в ПК ANSYS
Встроенных в текст программы физических констант нет. Все физико-механические, геометрические, жесткостные, инерционные и диссипативные характеристики задаются явно в исходных данных.

Официальные эксперты

Начальник отдела расчетов мостов
ЗАО "Институт Гипростроймост Санкт-Петербург"
д.т.н., проф. — Сливкер В.И.

Зав. кафедрой строительной механики
и вычислительных технологий
Пермского государственного
технического университета
д.т.н., проф. — Кашеварова Г.Г.

Зав. кафедрой «Инженерная и компьютерная графика»
Южно-Российского государственного
технического университета
д.т.н., проф. — Гайджуров П.П.

Председатель Научного Совета РААСН
"Программные средства в строительстве
и архитектуре",
д.т.н., проф. — Сидоров В.Н.

Москва, 2009 — 4

SOFTWARE SYSTEMS FOR ANALYSIS OF LOADS AND EFFECTS, STRENGTH AND STABILITY OF STRUCTURES, BUILDINGS AND COMPLEXES

РОССИЙСКАЯ АКАДЕМИЯ АРХИТЕКТУРЫ И СТРОИТЕЛЬНЫХ НАУК

Научный совет «Программные средства в строительстве и архитектуре»

СВИДЕТЕЛЬСТВО

№ 05/SIMULIA Abaqus/2014

о верификации программного средства, применяемого для решения задач теплопроводности и фильтрации, определения статического, температурного и динамического напряженно-деформированного состояния конструкций, зданий и сооружений

Программное средство: **SIMULIA Abaqus** – универсальный программный комплекс для решения задач теплопроводности и фильтрации, определения статического, температурного и динамического напряженно-деформированного состояния пространственных конструкций, зданий и сооружений с учётом эффектов физической, геометрической, структурной и генетической нелинейностей на основе метода конечных элементов (в том числе, совместно с методом конечных объёмов Эйлера) и бессеточного метода сглаженных частиц.

Разработчик: **Dassault Systèmes** (Франция)

Заявители: **ФГБОУ ВПО «МГСУ»** (Россия), **ООО «ТЕСИС»** (Россия)

Авторы верификационного отчёта: **ФГБОУ ВПО «МГСУ»** (Россия)

Дата включения в реестр верифицированных программных средств: **20 марта 2014 года**

Срок действия свидетельства: до **20 марта 2024 года**

Перечень верифицированных возможностей программного средства **SIMULIA Abaqus** изложен в Приложении (5 стр.), являющемся неотъемлемой частью Свидетельства, и в верификационном отчёте (4 тома на 610 стр.).

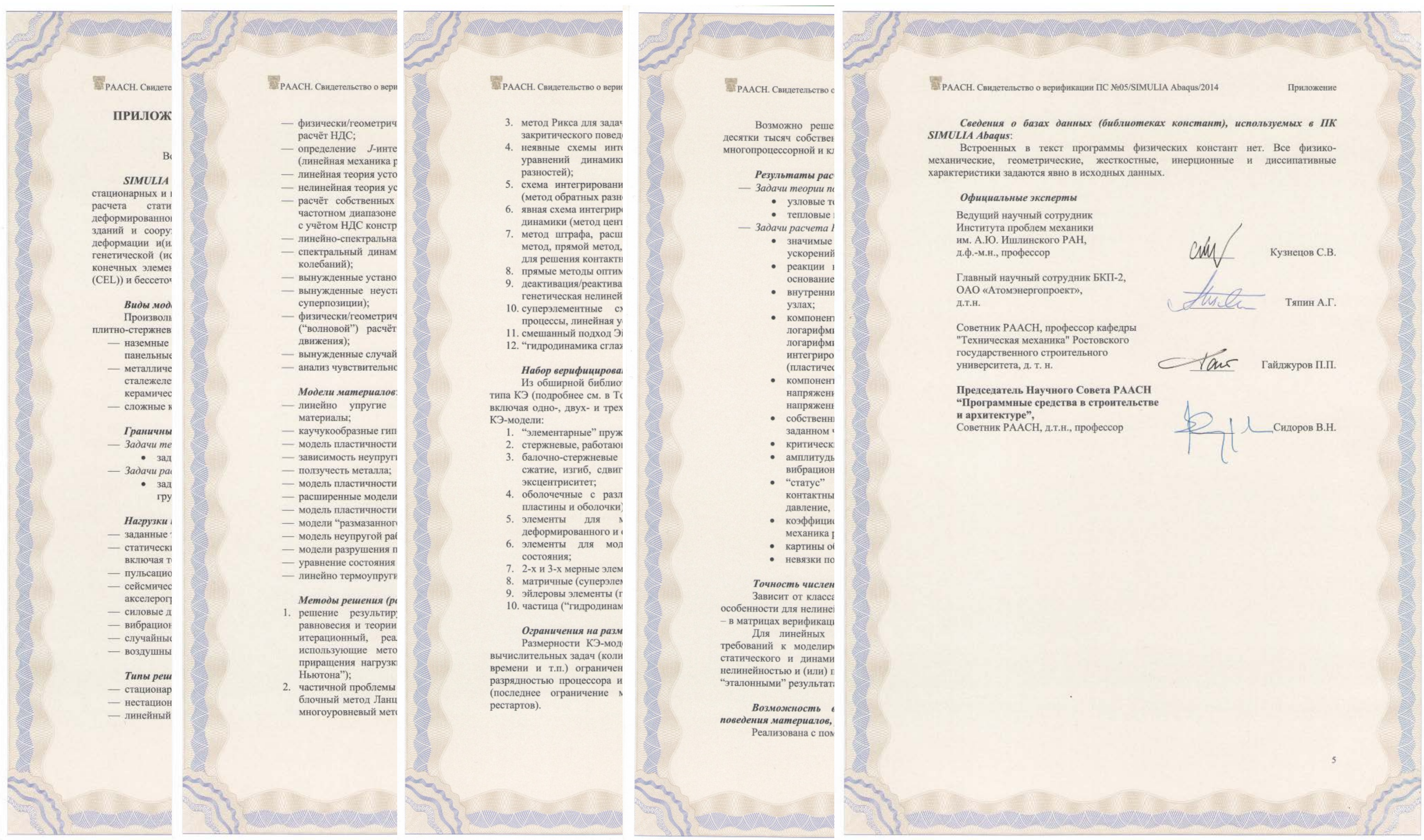
Вице-президент В.И. Травуш

Академик-секретарь Н.И. Карпенко

Председатель Научного Совета В.Н. Сидоров

Verification of SIMULIA Abaqus in the system of the Russian Academy of Architecture and Construction Sciences

SOFTWARE SYSTEMS FOR ANALYSIS OF LOADS AND EFFECTS, STRENGTH AND STABILITY OF STRUCTURES, BUILDINGS AND COMPLEXES


РААСН. Свидетельство о верификации ПС №05/SIMULIA Abaqus/2014 Приложение

***Сведения о базах данных (библиотеках констант), используемых в ПК SIMULIA Abaqus*:**

Встроенных в текст программы физических констант нет. Все физико-механические, геометрические, жесткостные, инерционные и диссипативные характеристики задаются явно в исходных данных.

Официальные эксперты

Ведущий научный сотрудник
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Главный научный сотрудник БКП-2,
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Председатель Научного Совета РААСН
“Программные средства в строительстве
и архитектуре”,
Советник РААСН, д.т.н., профессор — Сидоров В.Н.

5

MATRICES OF VERIFICATION

Functional capabilities (SIMULIA Abaqus)

Functional capabilities	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25	Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
Linear static analysis			•	•		•		•	•		•				•															
Linear quasi-static analysis			•												•															
Geometrically nonlinear static analysis																•	•	•				•								
Physically nonlinear static analysis														•								•				•				•
Physically nonlinear quasi-static analysis																										•				•
Contact interaction with a small relative displacement of the contacting surfaces															•							•			•			•		
Linear stability analysis							•													•										
Postbucking analysis																		•		•										
Frequency analysis										•																				
Uncoupled heat conduction problems					•																									
Modal analysis	•	•																												
Modal analysis with allowance for stress-strain state																•														
Random forced vibration												•																		
Forced steady-state vibration													•																	
Forced unsteady vibration																					•									

MATRICES OF VERIFICATION

Functional capabilities (SIMULIA Abaqus)

Functional capabilities	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25	Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
Geometrically nonlinear quasi-static analysis with allowance for loading history																							•							
Physically nonlinear quasi-static analysis with allowance for loading history																			•				•							
Geometrically nonlinear dynamic analysis																					•									
Geometrically and physically nonlinear dynamic analysis																								•	•		•	•	•	
Design sensitivity analysis											•																			
Linear-elastic materials	•	•	•	•		•	•	•		•	•	•	•		•	•	•	•		•	•						•			
Thermal properties of materials					•																									
Orthotropic linear-elastic materials									•																					
Computing of *J*-integral						•																								
Allowance of cross-sectional warp of beam structures								•																						
Simulation of air and ground explosions (CONWEP)																													•	
Multipoint constraints (MPC)															•						•									
Subcycles															•															
Steady-state creep																			•											
Mooney-Rivlin model for rubber-like hyperelastic materials																						•								

MATRICES OF VERIFICATION

Functional capabilities (SIMULIA Abaqus)

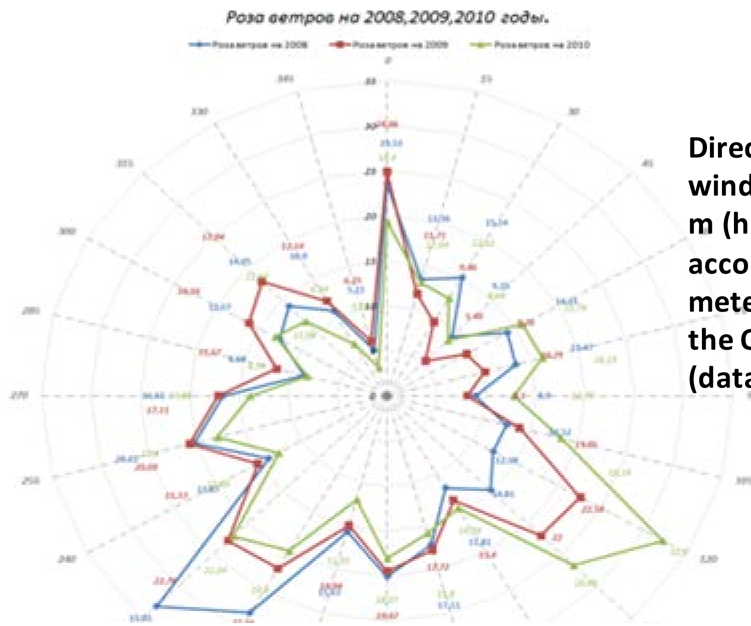
Functional capabilities	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25	Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
Ogden model for rubber-like hyperelastic materials																							•							
Mises plasticity model														•										•	•			•		
Drucker-Prager advanced plasticity and creep models																									•					•
Johnson-Cook plasticity model																													•	
Mohr-Coulomb plasticity model																														•
Plasticity model of cast iron																														•
Dependence of inelastic properties on the rate of deformation																									•				•	
Fracture model for ductile metals																									•			•		
Mie-Gruneisen equation of state																									•		•	•		
Models of sloshing cracks formation in brittle materials																										•				
The mixed Euler-Lagrange approach (CEL)																											•	•		
Smoothed particle hydrodynamics (SPH)																												•		
User-specified materials																									•				•	
User-supplied subprograms																													•	

SAMPLES OF NUMERICAL MODELING

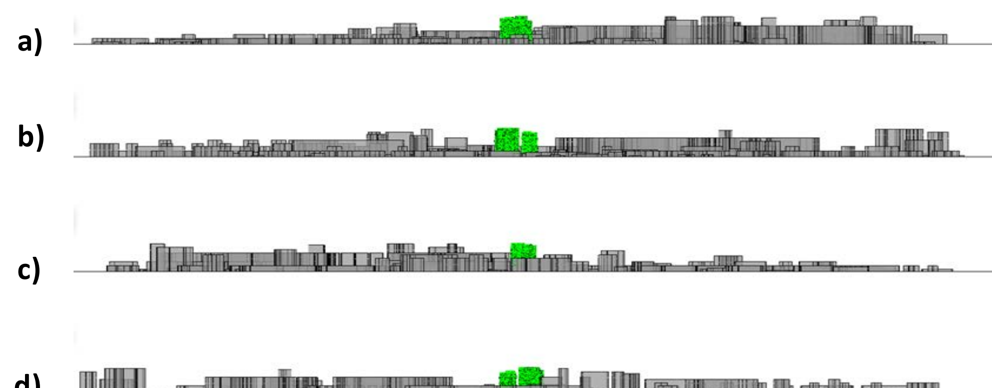
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)

Existing plan (maps.yandex.ru)

General view of the at the end of construction (draft)



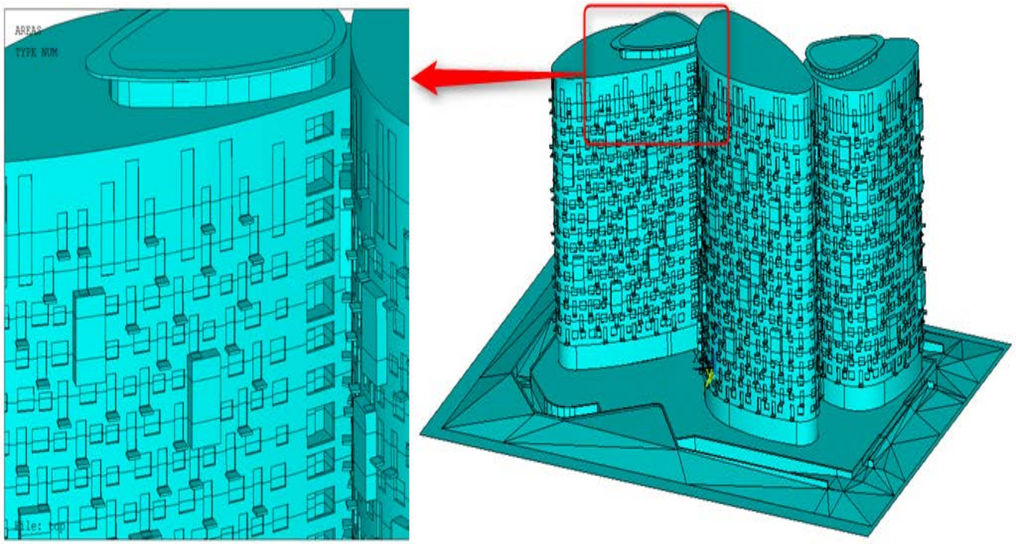
Direction and frequency of winds at an altitude of 300 m (hours per year) according to the meteorological station at the Ostankino TV Tower (data for 2008-2010)



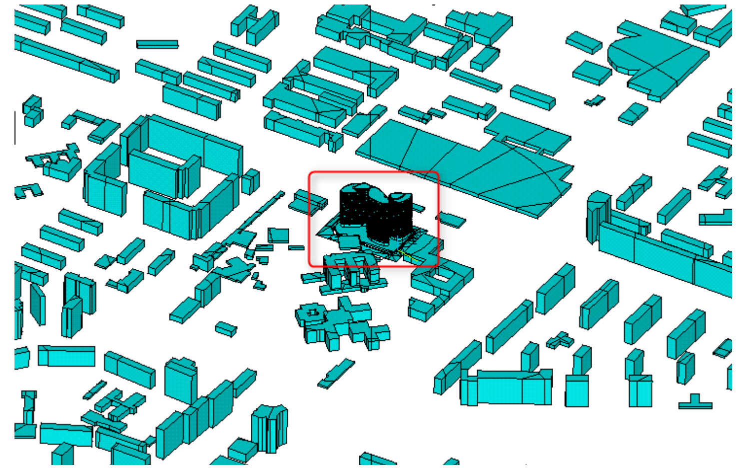
View of Complex (highlighted in green) and existing buildings:
a) From the North-West; b) From the Northeast;
c) From the South-East; d) From the South-West

SAMPLES OF NUMERICAL MODELING

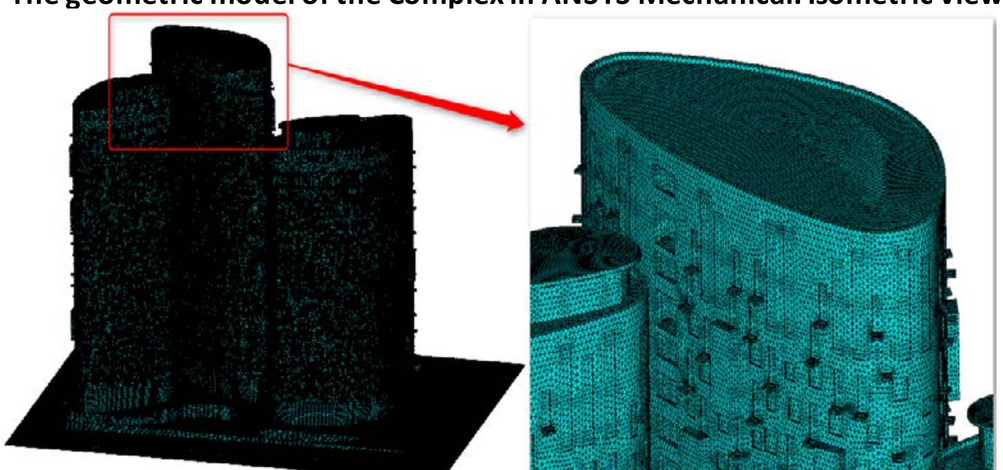
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)



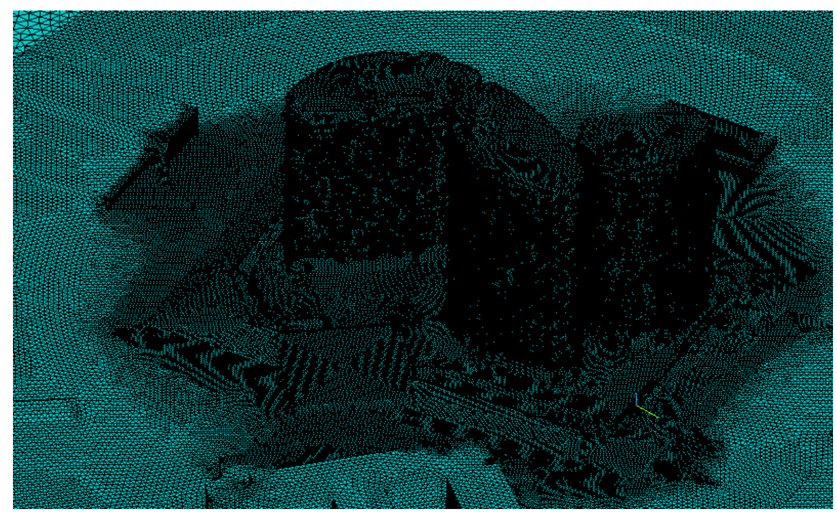
The geometric model of the Complex in ANSYS Mechanical. Isometric view



The geometric model of the Complex and existing buildings in ANSYS Mechanical. View from the South



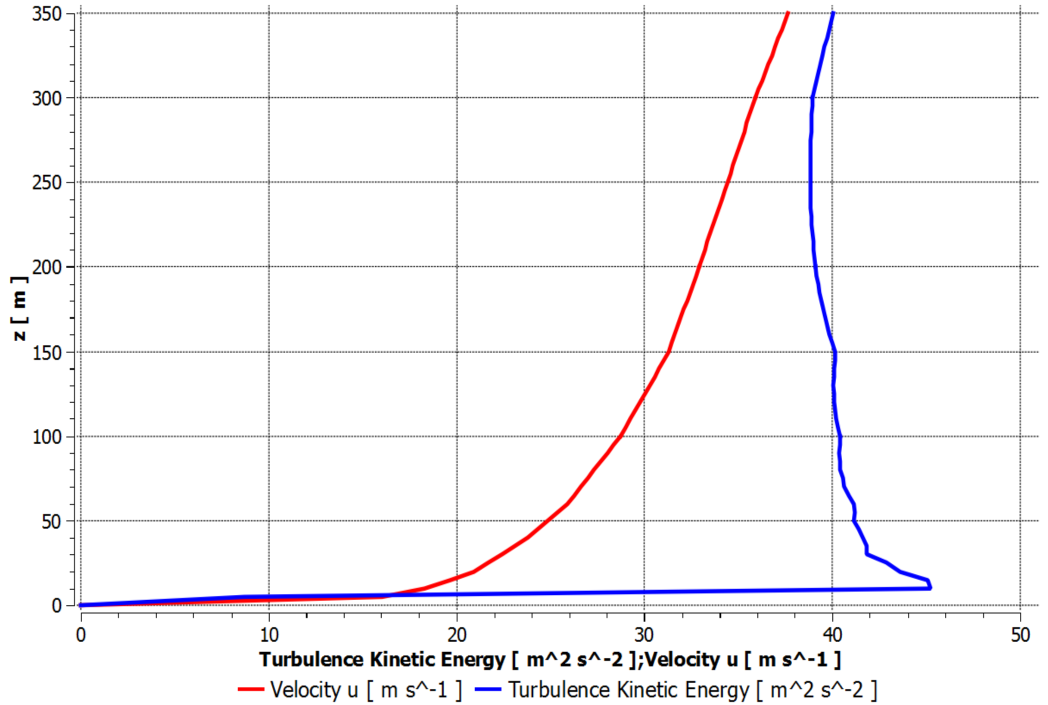
Mesh on the surfaces of the Complex (element size – 0.5 m). ANSYS CFD

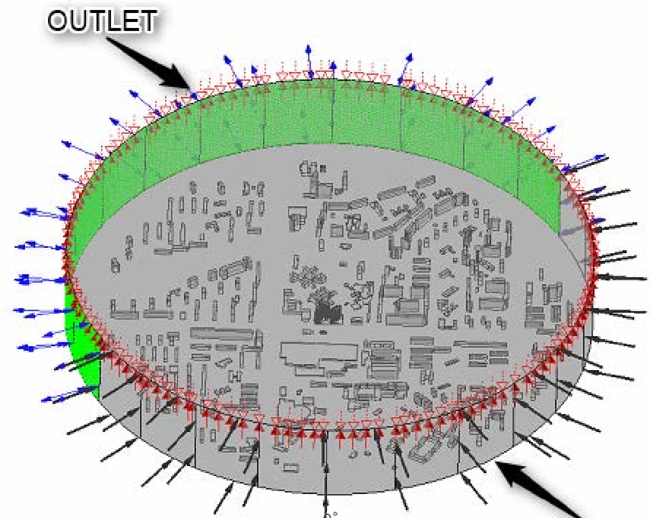


Mesh on the surfaces of the Complex (element size – 0.5 m). ANSYS CFD. The dimension of the full model is 10512839 nodes / finite volumes.

SAMPLES OF NUMERICAL MODELING

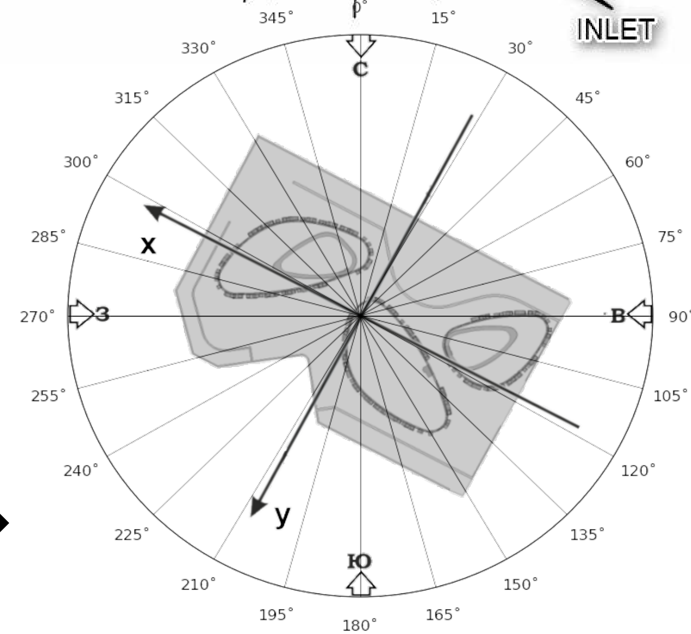
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)





Boundary conditions "at the inlet" (INLET). Profiles of the kinetic energy of turbulence TKE (blue line), м2/s2 and horizontal component of wind speed u (red line), m/s,

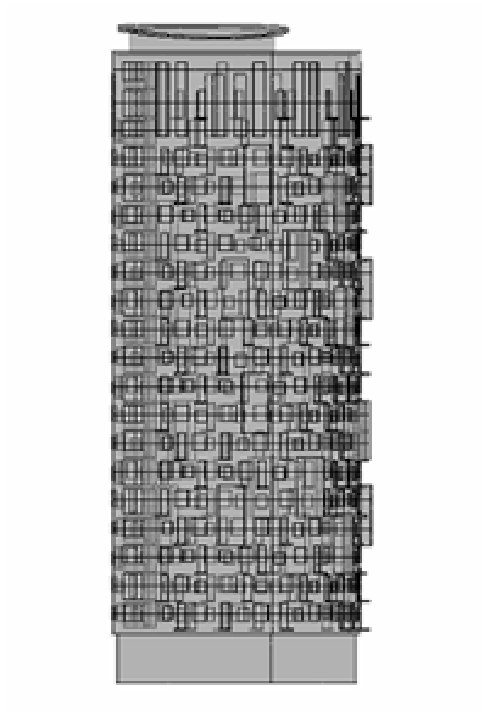
for *the first wind district, type of terrain B ("suburb")* in accordance with design codes SP 20.13330.2011 Loads and effects



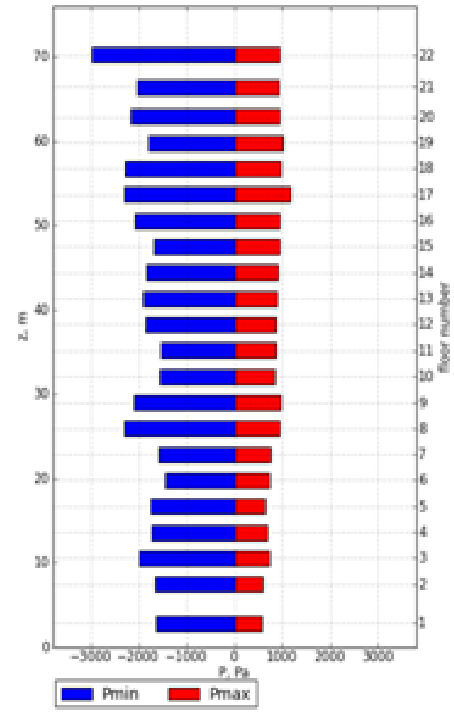
Model coordinate system of Complex and design wind directions (0° – "North", 90° – "East", 180° – "South", 270° – "Western")

SAMPLES OF NUMERICAL MODELING

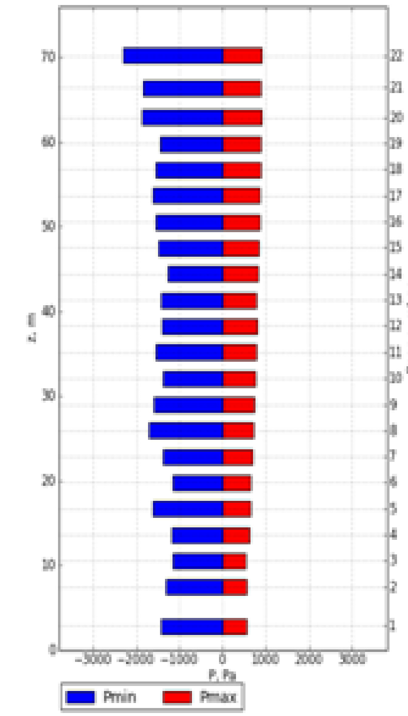
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, …) (ANSYS CFD)



a) Side view



b) Complex in the open fields



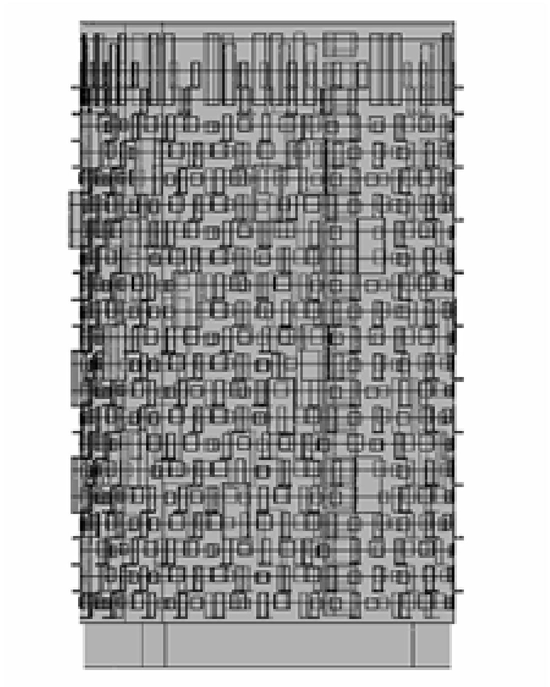
c) Complex and existing buildings

The floor envelopes of the minimum (Pmin) and maximum (Pmax) pressure values (Pa) on the facade structures of the building 1 of the Complex with allowance for wind directions

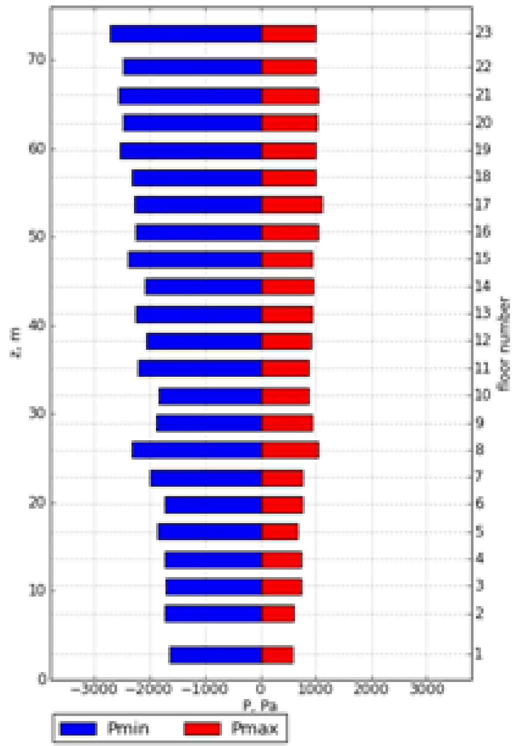
Wind loads on the facade of the Complex for the option of *full building* are reduced by 10% due to the interference of nearby structures ("shading" of the Complex).

SAMPLES OF NUMERICAL MODELING

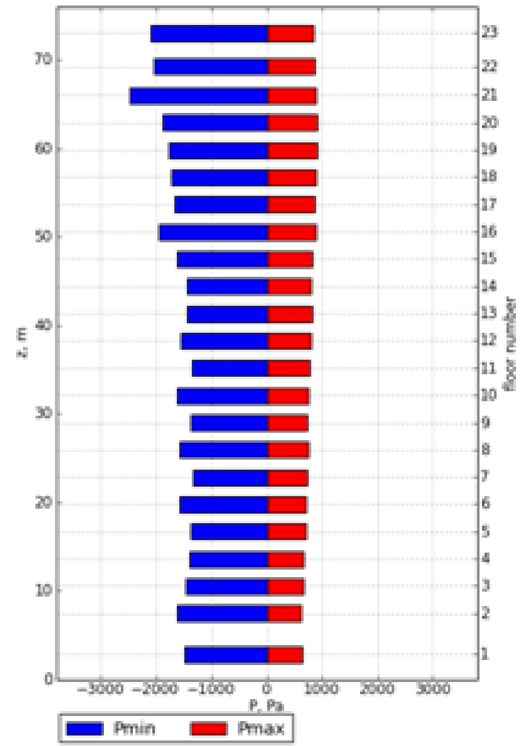
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)



a) Side view



b) Complex in the open fields



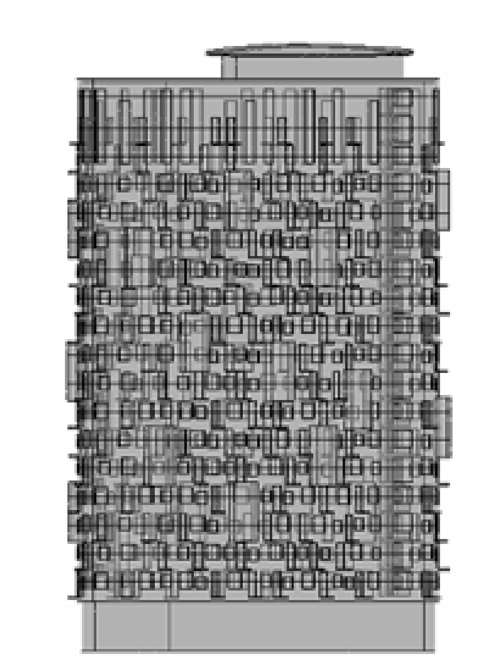
c) Complex and existing buildings

The floor envelopes of the minimum (Pmin) and maximum (Pmax) pressure values (Pa) on the facade structures of the building 2 of the Complex with allowance for wind directions

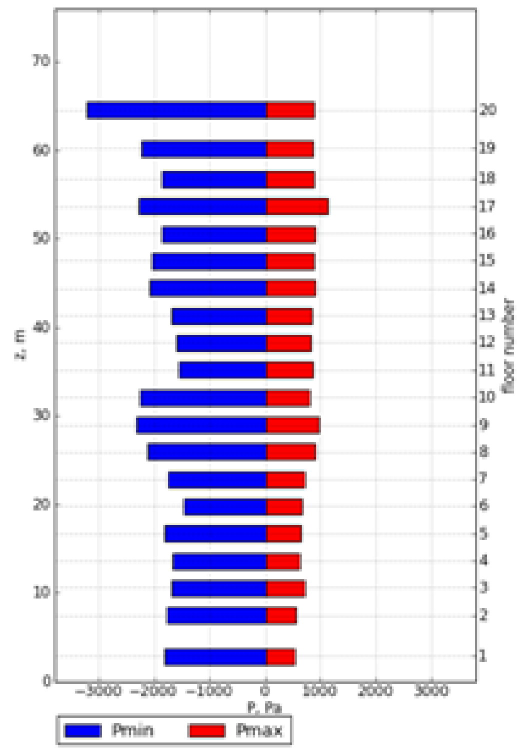
Wind loads on the facade of the Complex for the option of *full building* are reduced by 10% due to the interference of nearby structures ("shading" of the Complex).

SAMPLES OF NUMERICAL MODELLING

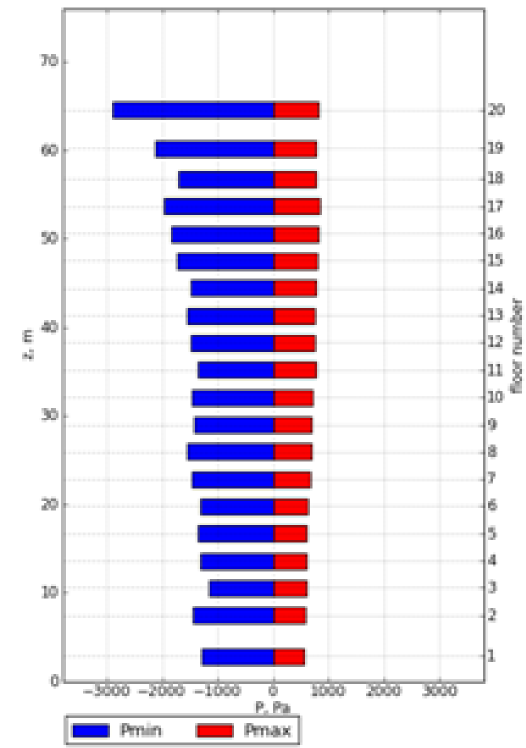
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)



a) Side view



b) Complex in the open fields



c) Complex and existing buildings

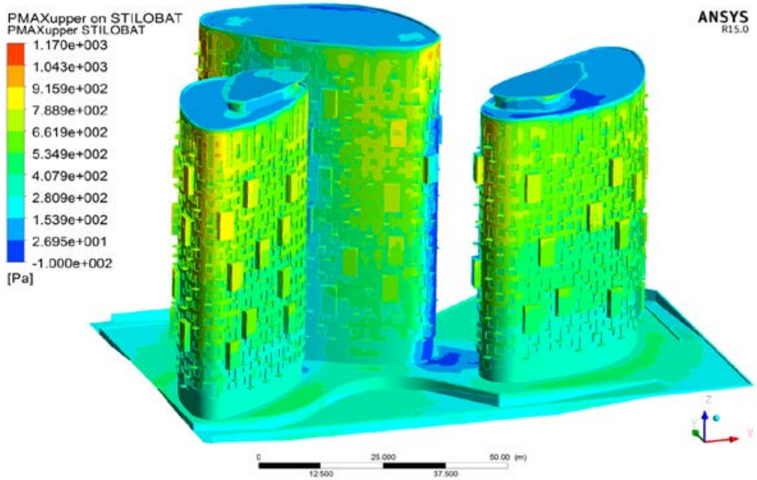
The floor envelopes of the minimum (Pmin) and maximum (Pmax) pressure values (Pa) on the facade structures of the building 3 of the Complex with allowance for wind directions

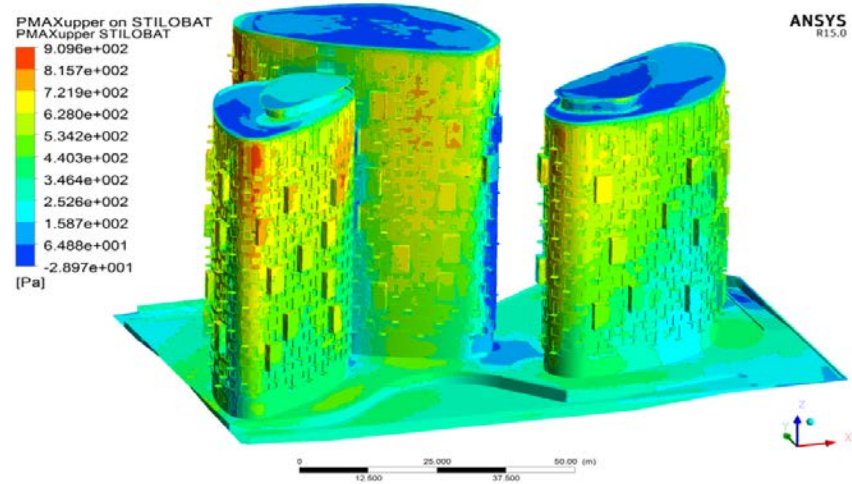
Wind loads on the facade of the Complex for the option of *full building* are reduced by 10% due to the interference of nearby structures (“shading” of the Complex).

SAMPLES OF NUMERICAL MODELING

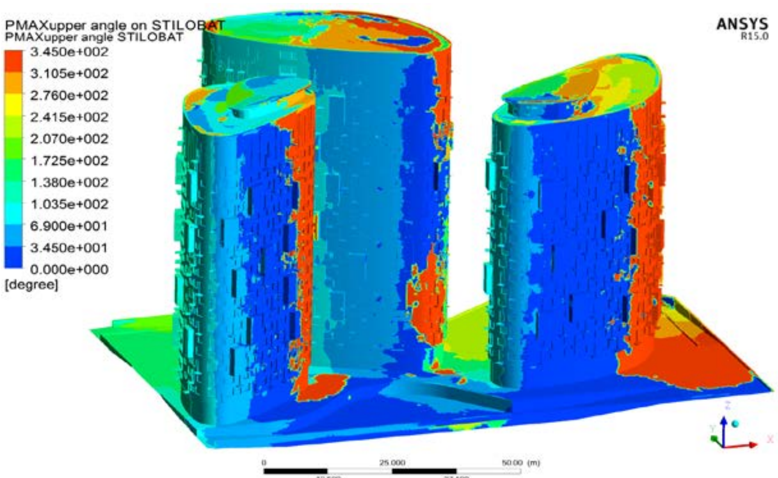
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)

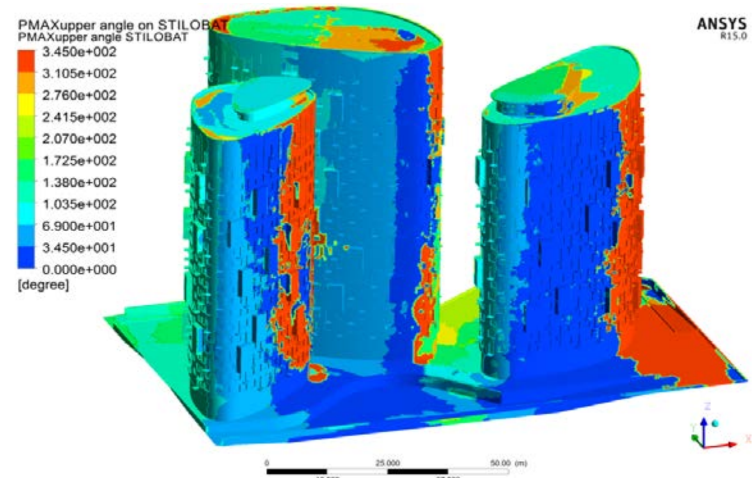
Isolated Complex | ***Complex and existing buildings***





The envelope of the maximum values of wind pressure (Pa) on the facade structures of the Complex.



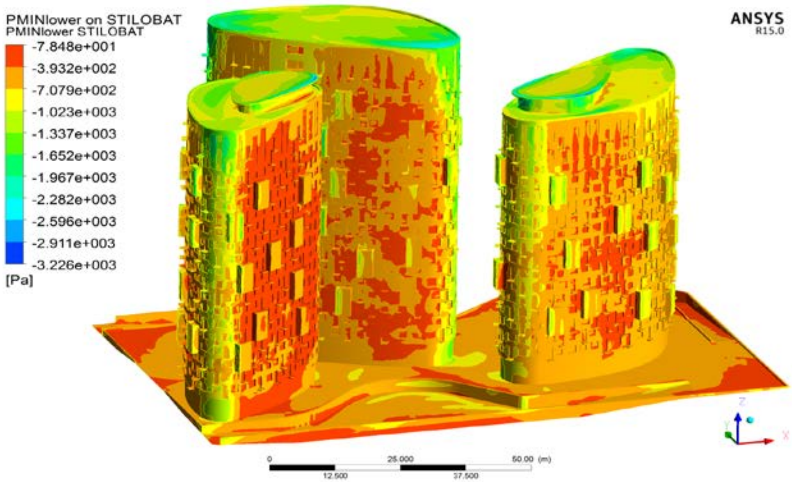


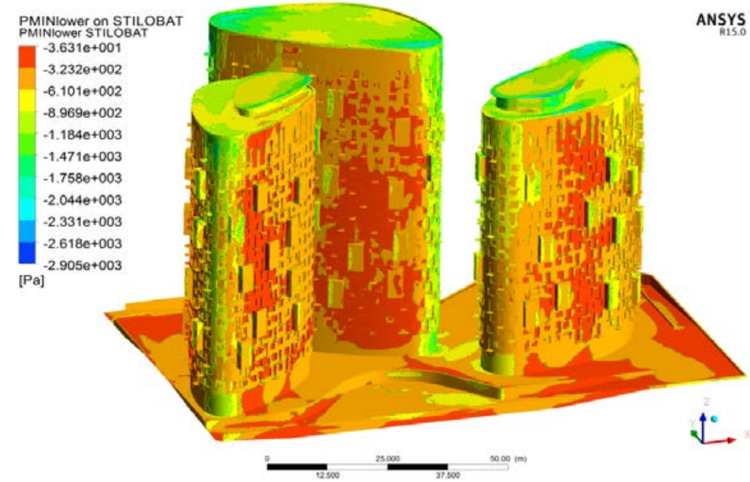
Angles of wind impact (°) at which the upper envelope of the maximum values of wind pressure is realized on facade structures of Complex

SAMPLES OF NUMERICAL MODELING

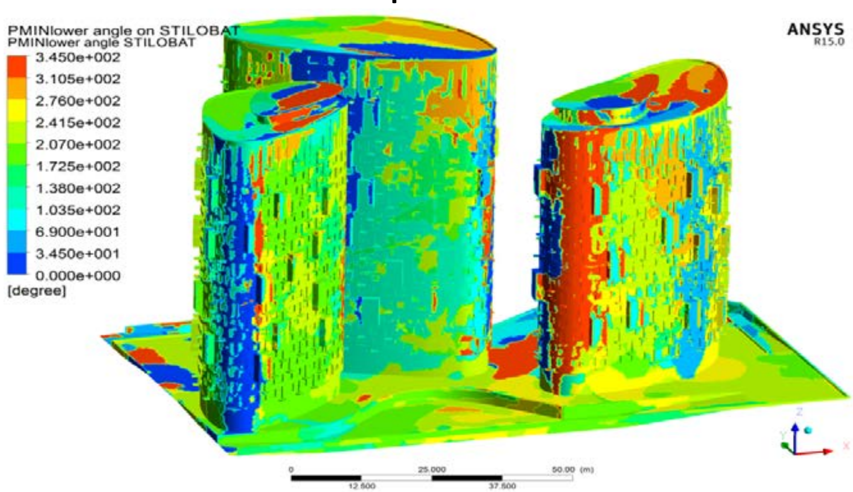
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)

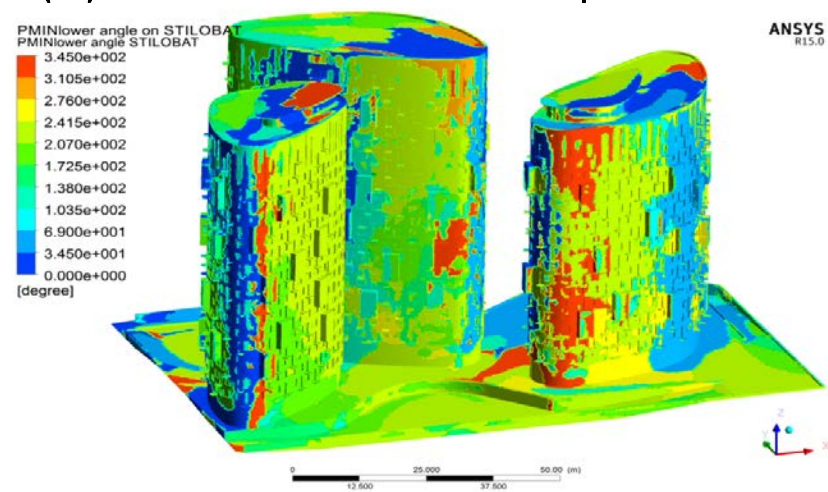
Isolated Complex ***Complex and existing buildings***





The envelope of the maximum values of wind pressure (Pa) on the facade structures of the Complex.

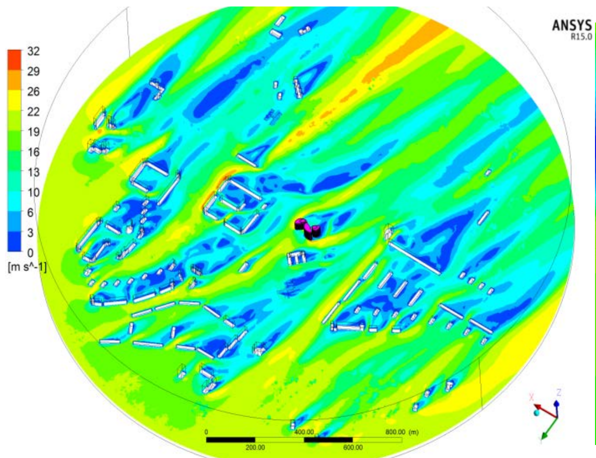




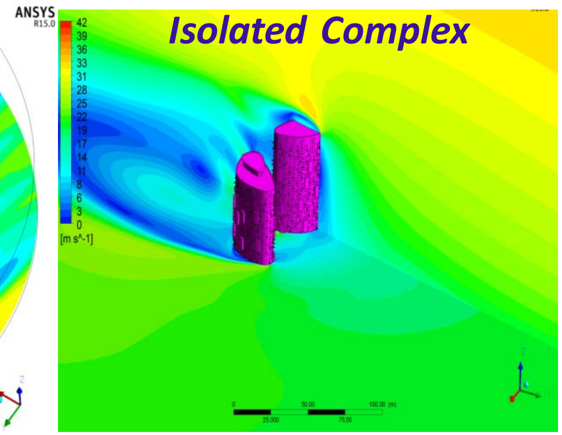
Angles of wind impact (°) at which the upper envelope of the minimum values of wind pressure is realized on facade structures of Complex

SAMPLES OF NUMERICAL MODELING

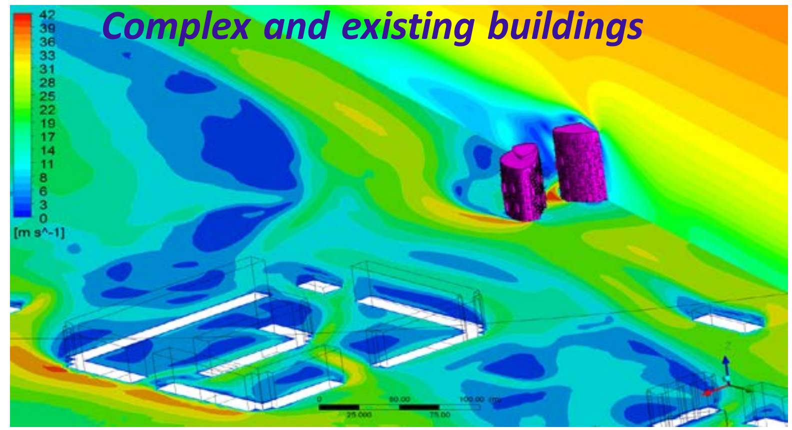
Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, …) (ANSYS CFD)



Isolated Complex

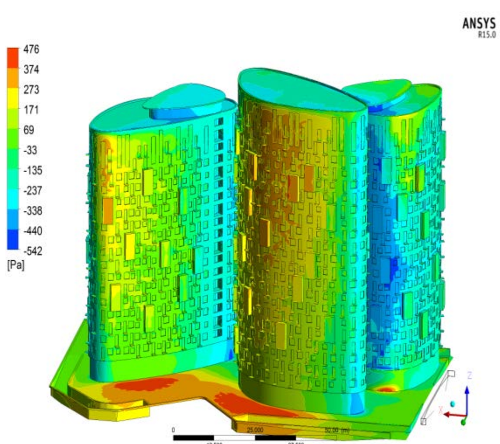


Complex and existing buildings

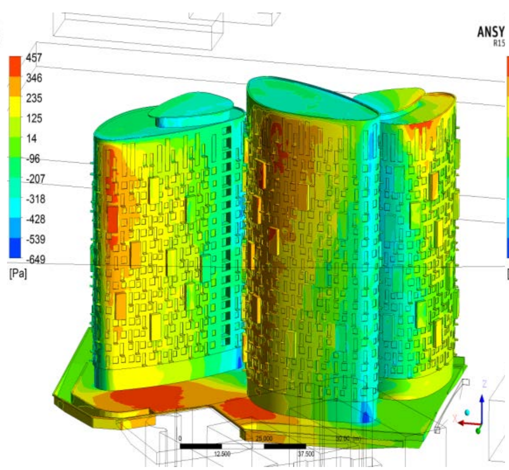


The average values of the wind speed (m/s) in the vertical plane of the wind and in the horizontal plane at a height of 20 m

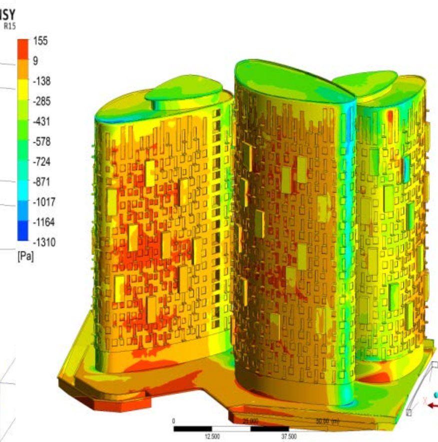
Isolated Complex



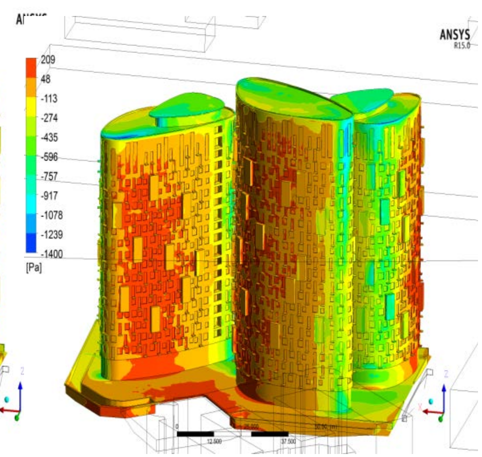
Complex and existing buildings



Isolated Complex



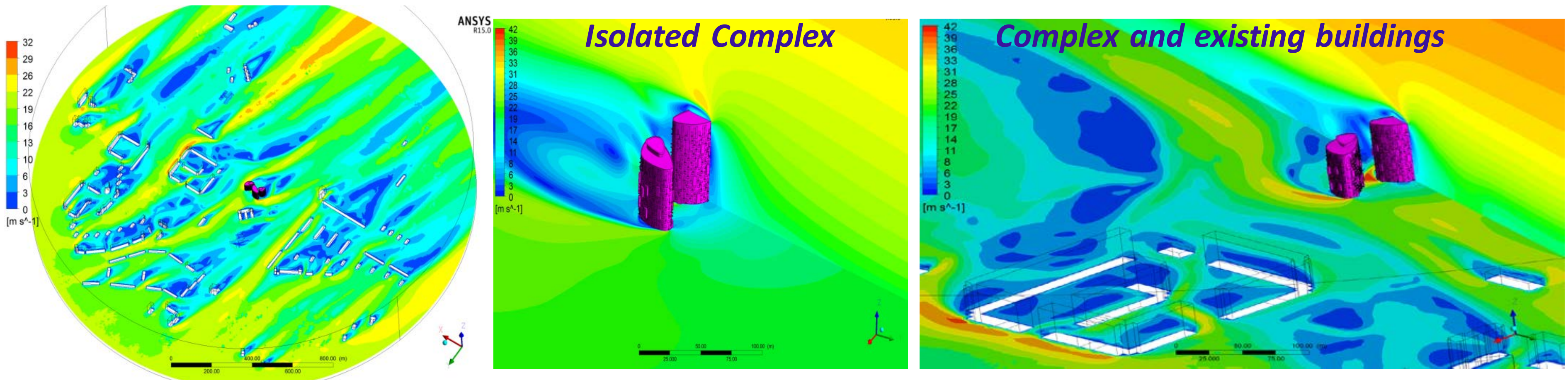
Complex and existing buildings



Maximum Values (Pa) **Minimum Values (Pa)**

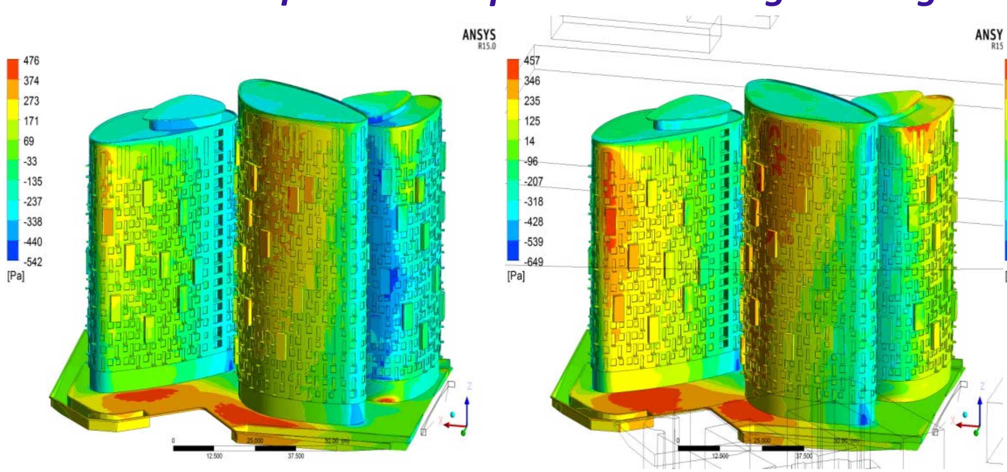
SAMPLES OF NUMERICAL MODELING

Computing of wind loads on the load-bearing and facade structures of a multi-storey complex with an apart-hotel (Moscow, Nakhimovsky Ave, ...) (ANSYS CFD)



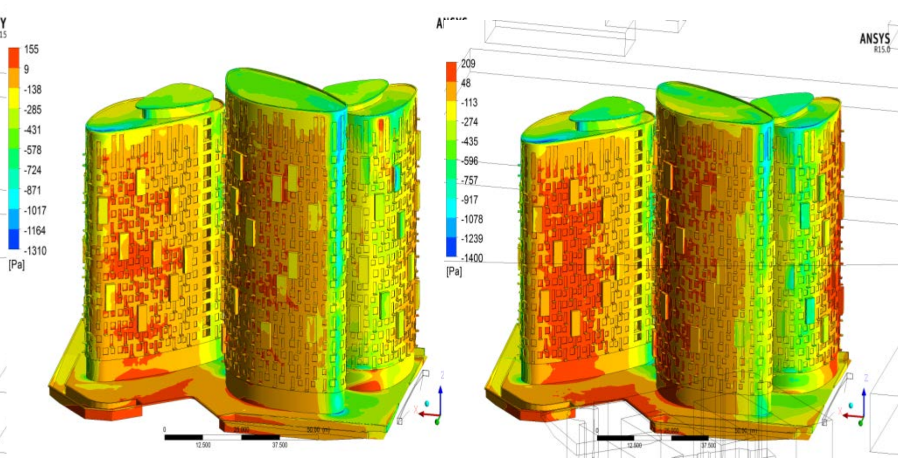
The average values of the wind speed (m/s) in the vertical plane of the wind and in the horizontal plane at a height of 20 m

Isolated Complex | *Complex and existing buildings*



Maximum Values (Pa)

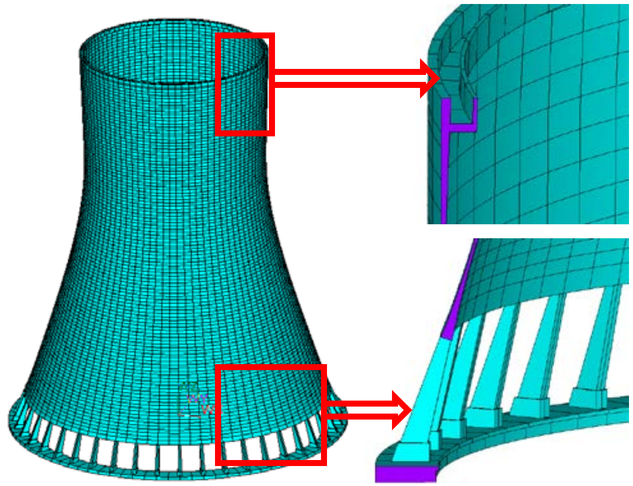
Isolated Complex | *Complex and existing buildings*



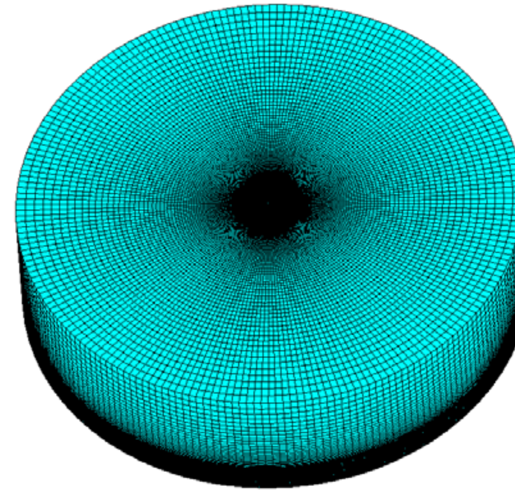
Minimum Values (Pa)

SAMPLES OF NUMERICAL MODELING

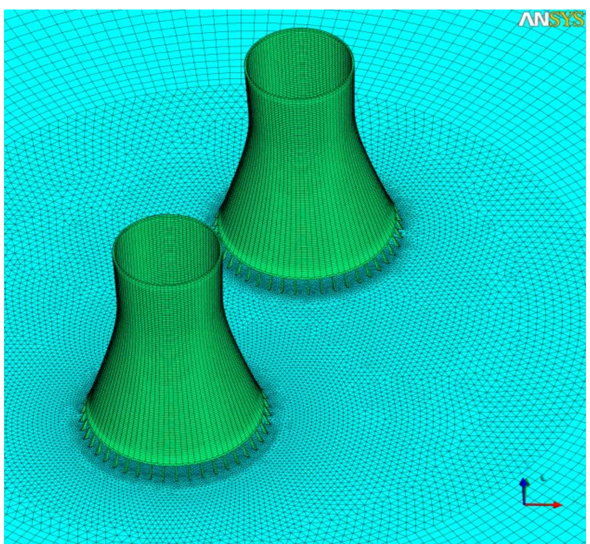
Wind aerodynamics. Evaporative cooling towers of Novovoronezh nuclear power plant – 2. Three-dimensional CFD-model (ANSYS CFD)



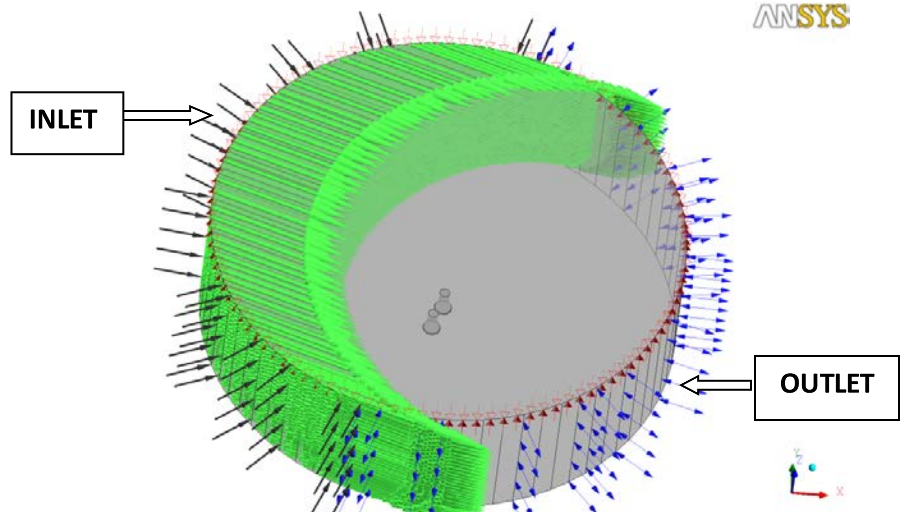
Geometrical model *Section along the axis of symmetry*



Computational domain (5.28 millions of elements)



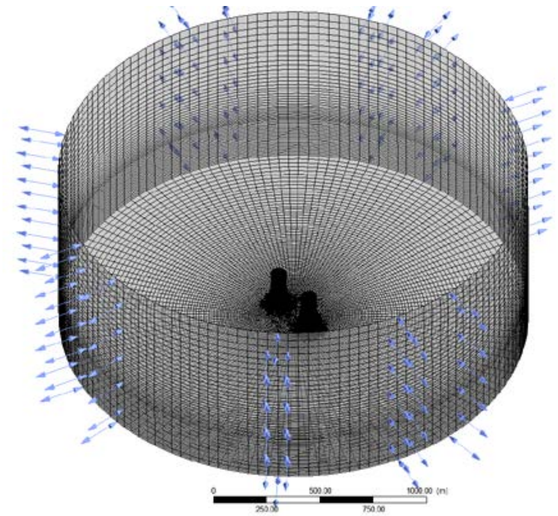
Surface mesh on cooling towers (model with 5.28 million of elements)

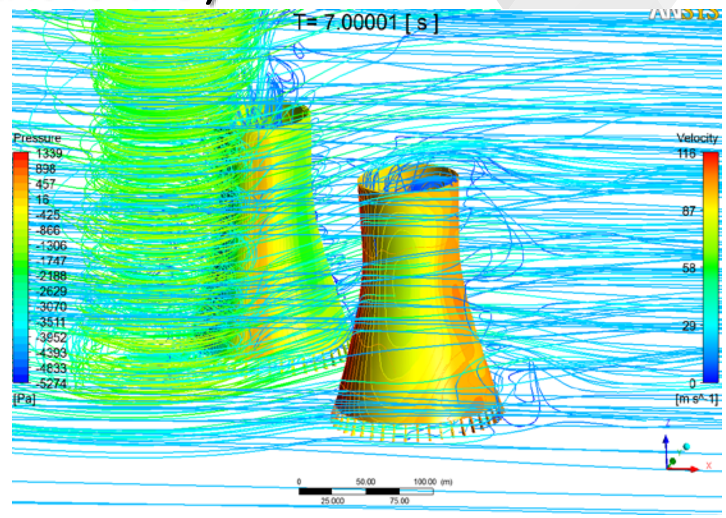


Computational domain with the indicated boundary conditions. Angle of wind impact 0°

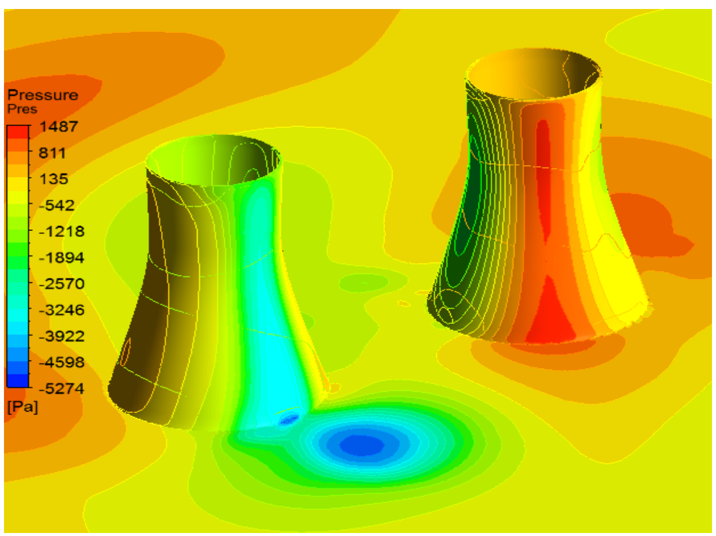
SAMPLES OF NUMERICAL MODELING

Wind aerodynamics. Evaporative cooling towers of Novovoronezh nuclear power plant – 2. Analysis of the impact of a tornado (ANSYS CFD)

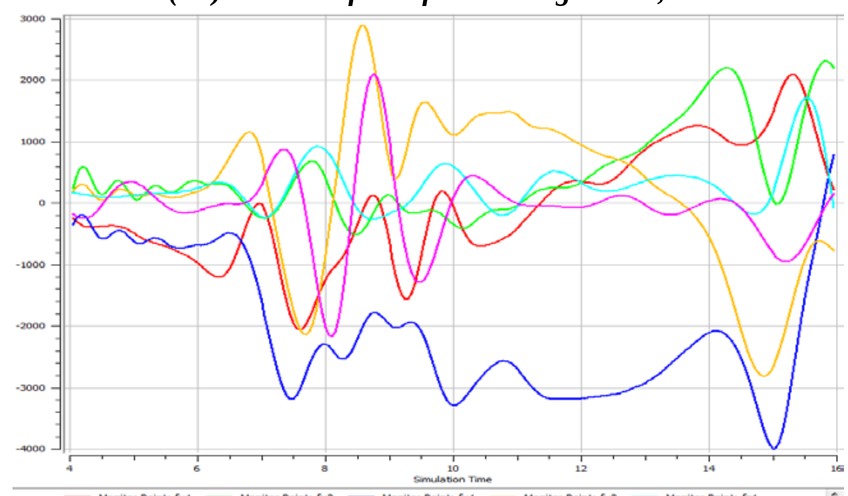




The time is 7 seconds after the start of the "movement" of the tornado. Pressure (Pa) on the surface of the cooling towers, линии тока



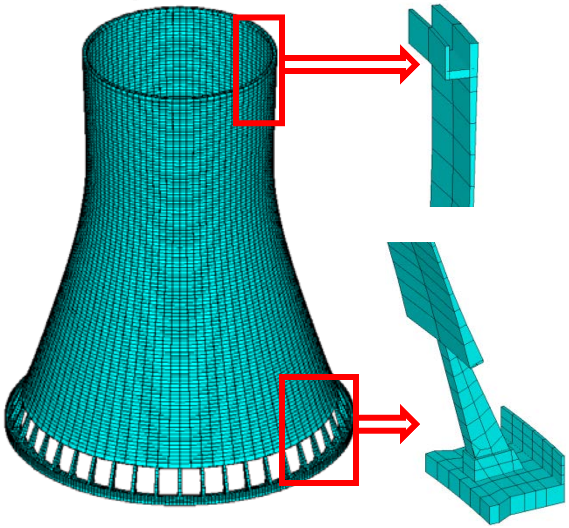
The time is 7 seconds after the start of the "movement" of the tornado. Pressure (Pa) on the surface of the cooling towers and on the plane z = 10 m



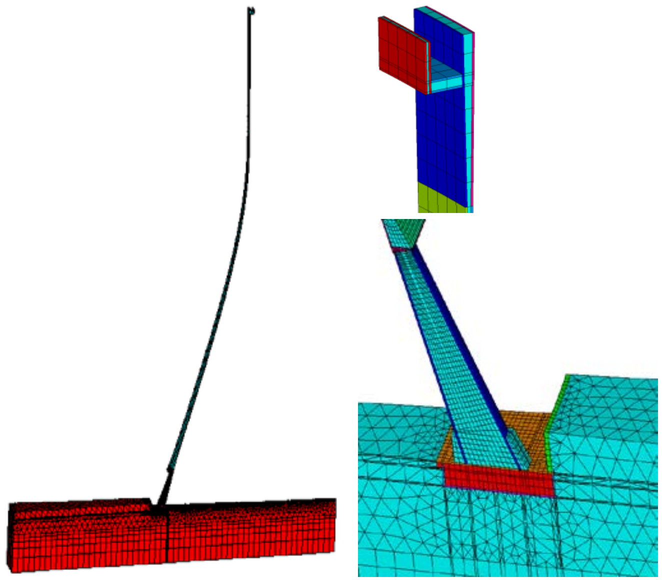
Total loads (ton-force) FX and FY on the first and the second cooling towers caused by tornado (s)

SAMPLES OF NUMERICAL MODELING

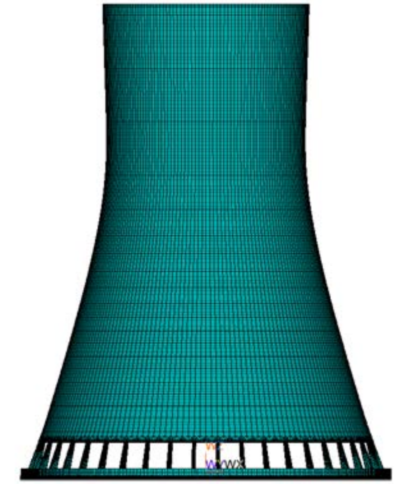
Stress-strain state, strength and stability of cooling towers of Novovoronezh nuclear power plant – 2. Computational finite element models (ANSYS)



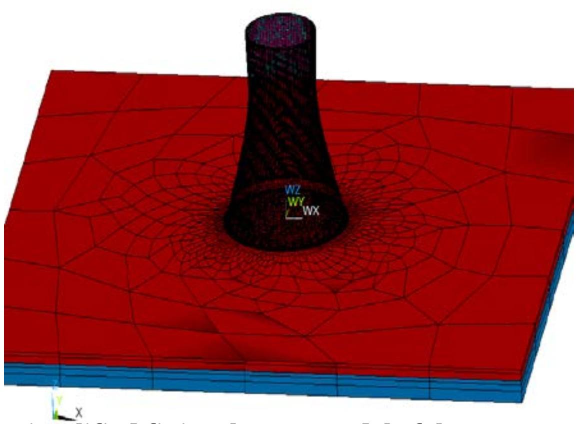
Shell finite element model (14 000 nodes)



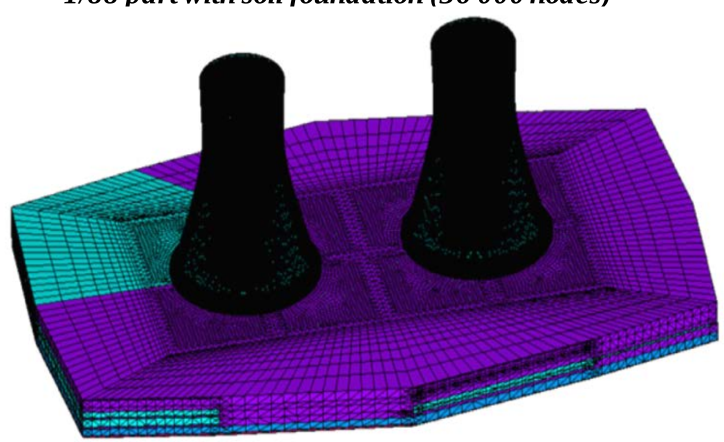
Three-dimensional finite element model of sector 1/88 part with soil foundation (36 000 nodes)



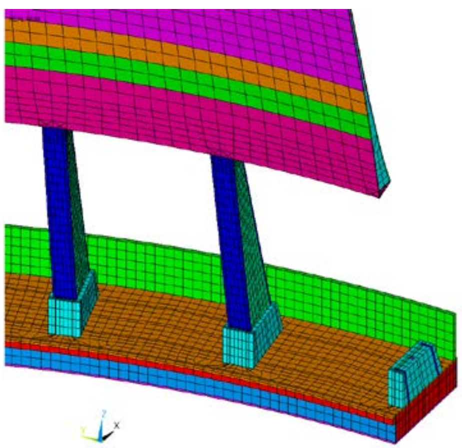
Three-dimensional finite element model (724 000 nodes)



Simplified finite element model of the system "Dynamic soil foundation – cooling tower (shell) with allowance for contact interaction (35 000 nodes)



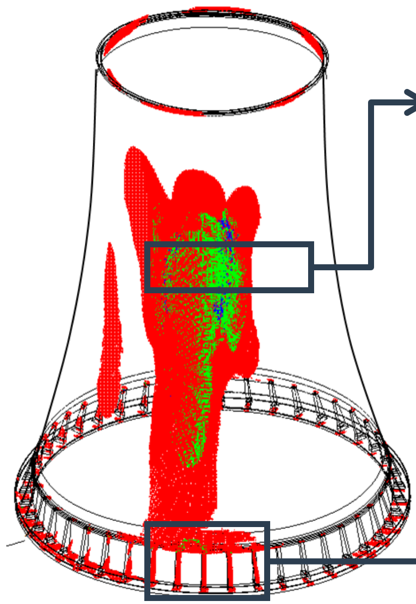
Three-dimensional finite element model of system "soil foundation – cooling tower" (1 300 000 nodes)



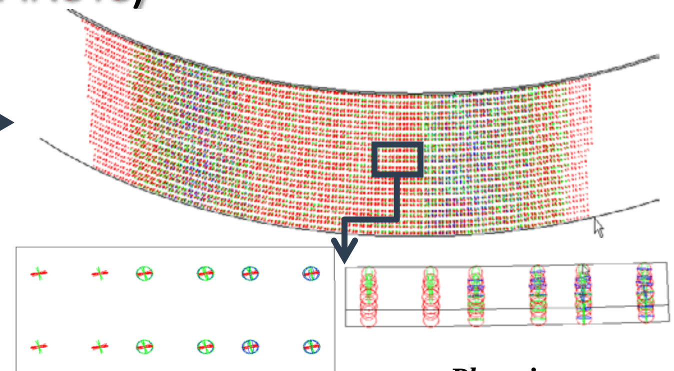
Three-dimensional finite element model for analysis of emergency situation (49 000 nodes)

SAMPLES OF NUMERICAL MODELING

Nonlinear structural analysis of cooling towers of Novovoronezh nuclear power plant – 2 in case of tornado (ANSYS)

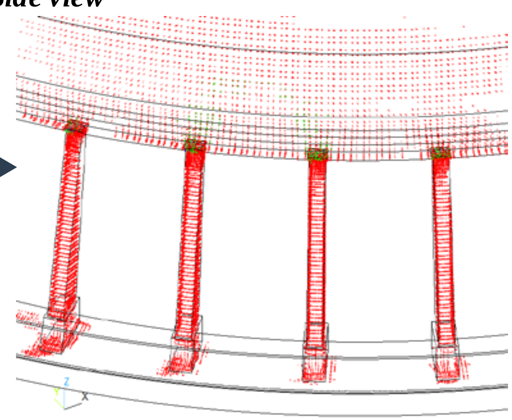


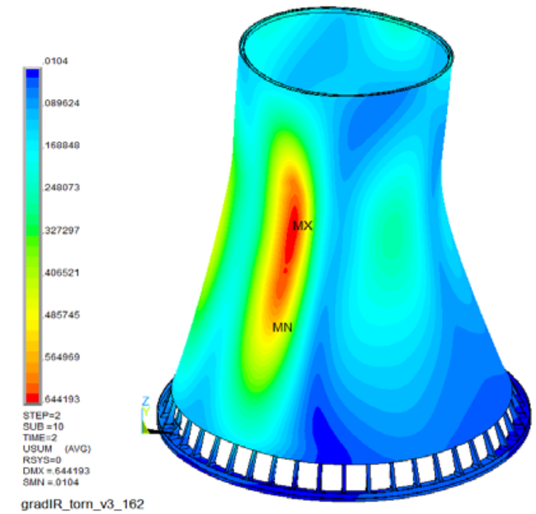
Cracking Scheme



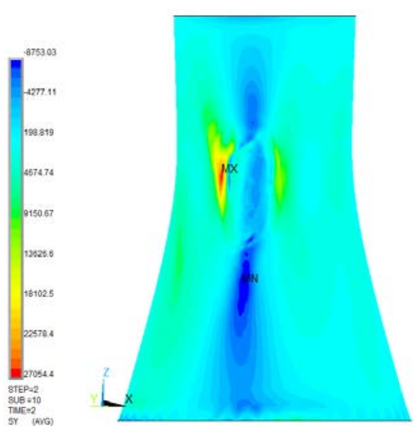
Side view

Plan view

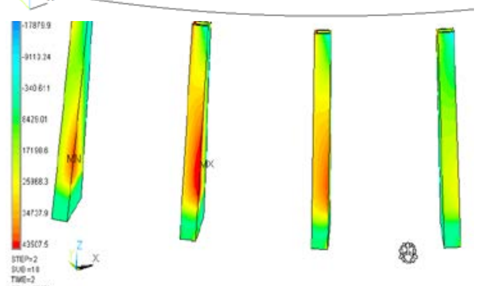




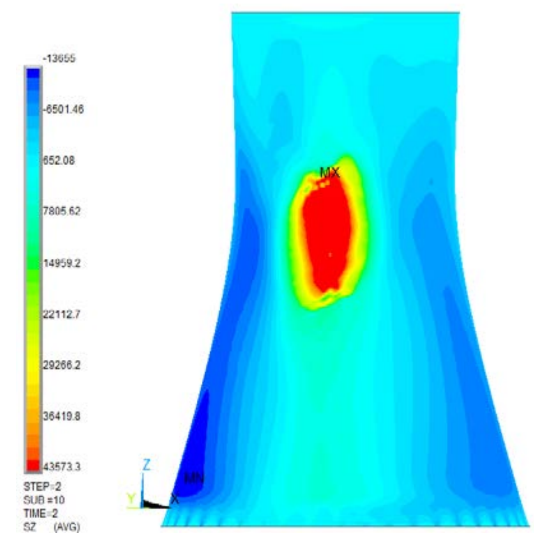
The total displacement, Maximum value 0.64 m



Stress (tnf/m²) in lateral reinforcement of shell. From -8753 to 27054 tnf/m²



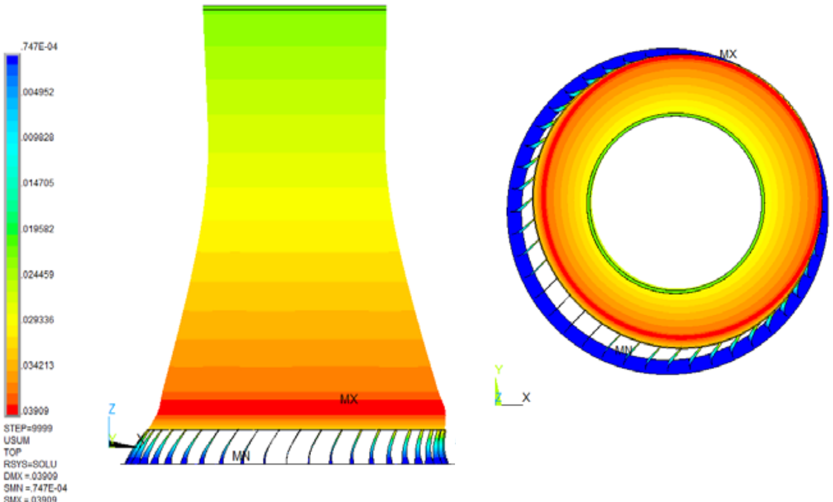
Stress (tnf/m²) in column reinforcement. From -26650 to 43507 tnf/m²



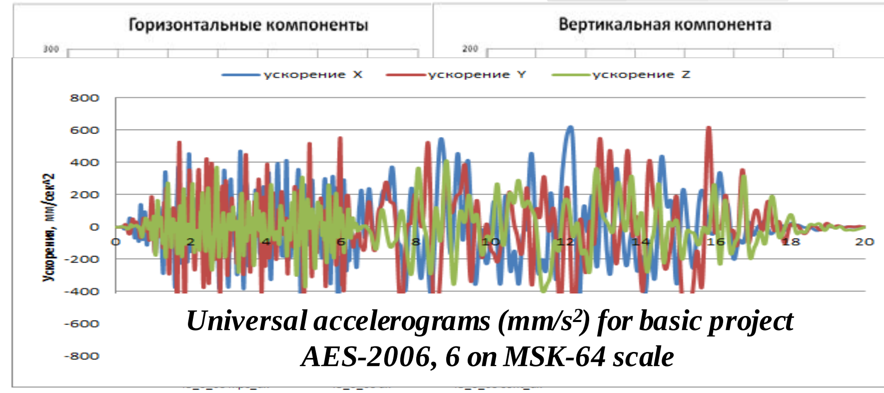
Stress (tnf/m²) in meridional reinforcement of shell. From -13655 to 43573 tnf/m²

SAMPLES OF NUMERICAL MODELING

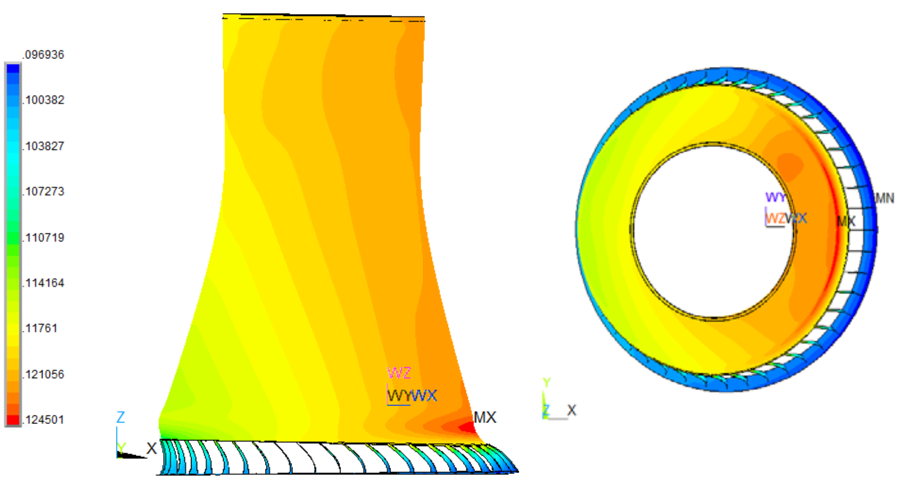
Seismic analysis of cooling towers of Novovoronezh nuclear power plant – 2 (ANSYS)



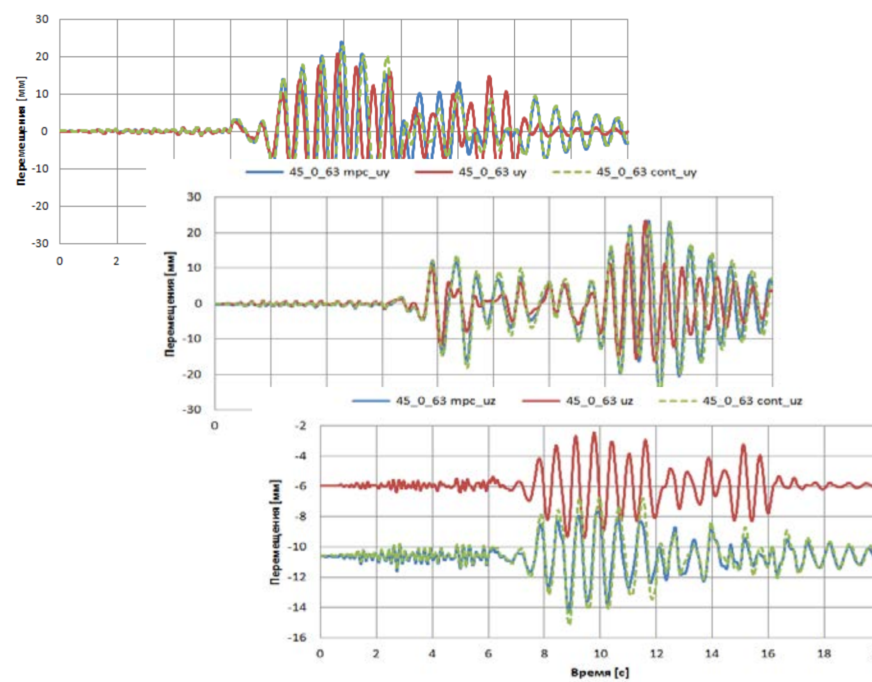
The total displacement, maximum value 0.039 m
Analysis with the use of linear-spectral method



Universal accelerograms (mm/s²) for basic project
AES-2006, 6 on MSK-64 scale



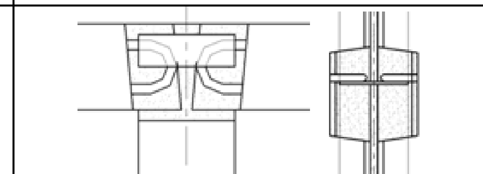
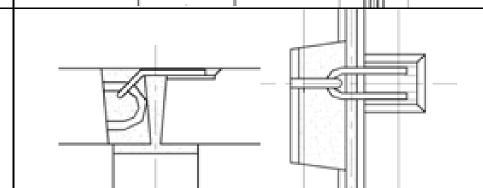
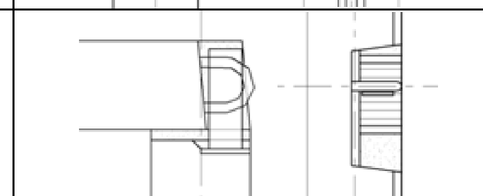
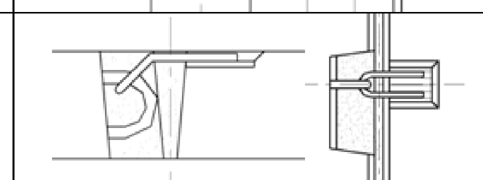
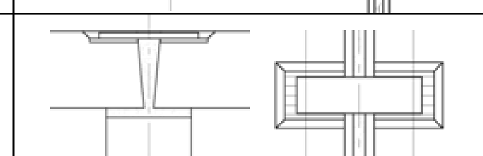
Total displacement (m) at the time t = 8.85 s.
Structural analysis with allowance of accelerogram
based on direct dynamic method



Nodal displacements UX, UY, UZ (mm) at a height of 63 m relative to base (for three formulations): blue line – "continuous" MPC contact, red line – rigid foundation, green dashed line – standard contact

SAMPLES OF NUMERICAL MODELING

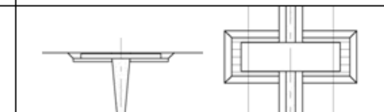
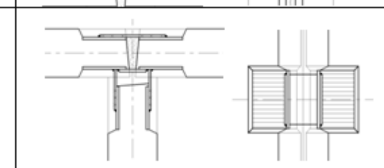
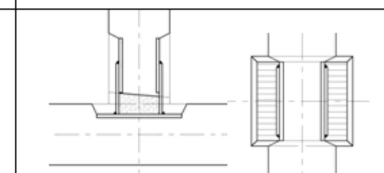
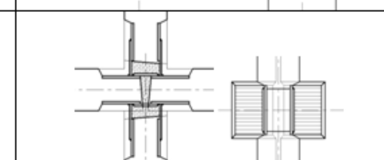
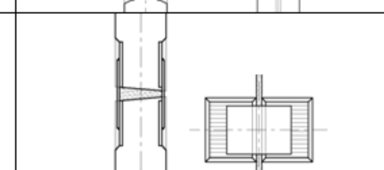
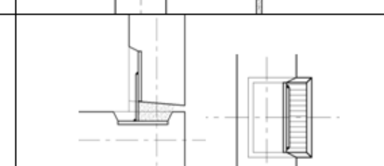
Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

№	Обозначение, количество	Чертеж
1	П-1, 862	
2	П-2, 1510	
3	П-3, 54	
4	П-4, 108	
5	П-5, 432	

Embedded part s identification scheme

SAMPLES OF NUMERICAL MODELING

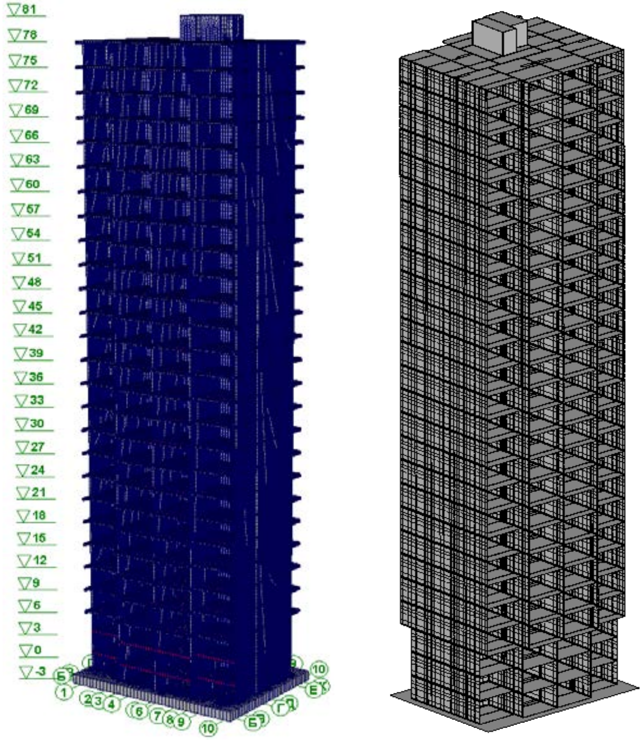
Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

№	Обозначение, количество	Чертеж
5	П-6, 756	
7	С-1, 270	
8	С-2, 1674	
9	С-3, 486	
10	С-4, 486	
11	С-12, 324	

Embedded part s identification scheme

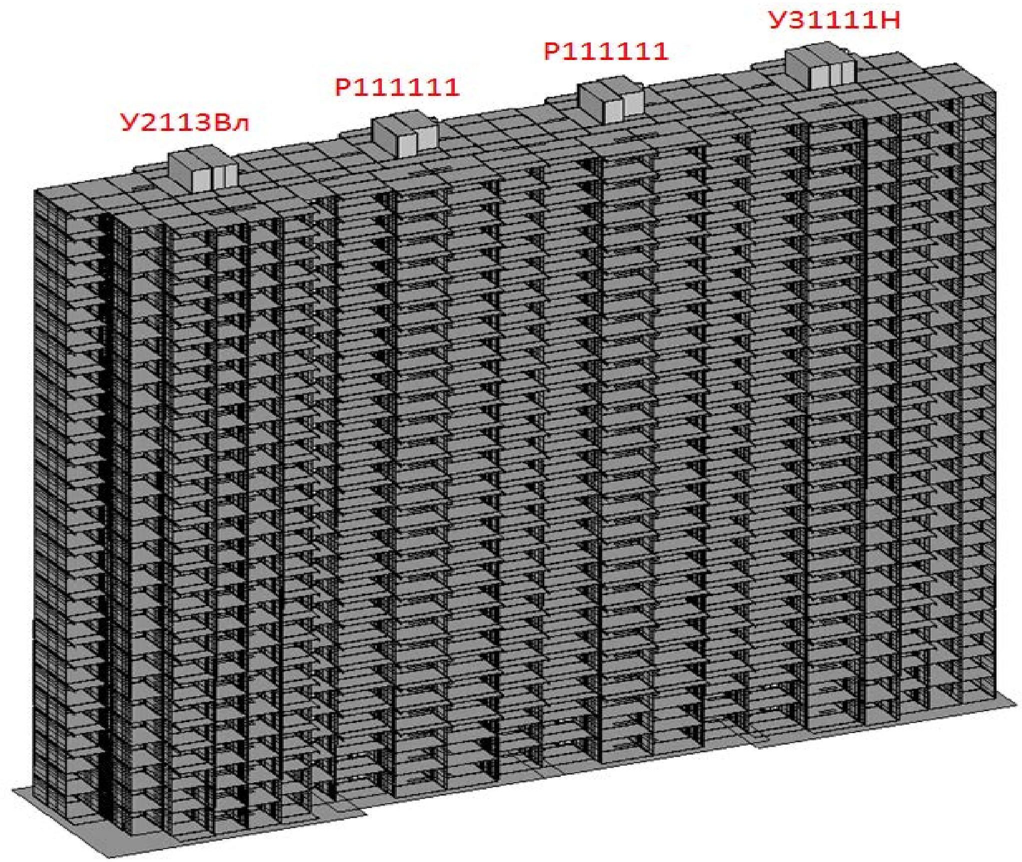
SAMPLES OF NUMERICAL MODELING

Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

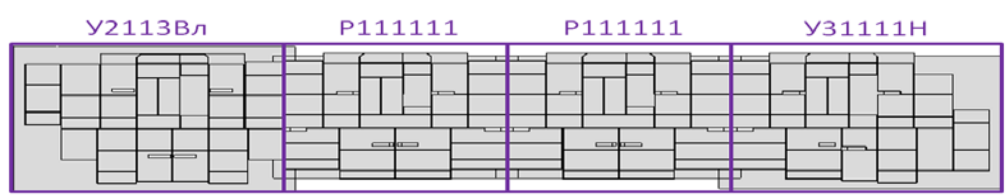


Isometric views of finite element models of module of apartment house

No.	Description	Number of nodes	Number of elements
1	*Section И-155СП-Р111111*	542 620	566 030
2	*Section И-155СП-У11113Нл*	595 128	621 704
3	*Section И-155СП-У31111Н*	594 004	619 751
4	*Section И-155СП-У2113Вл*	611 369	640 605
5	*Temperature module*	2 218 978	2 313 738

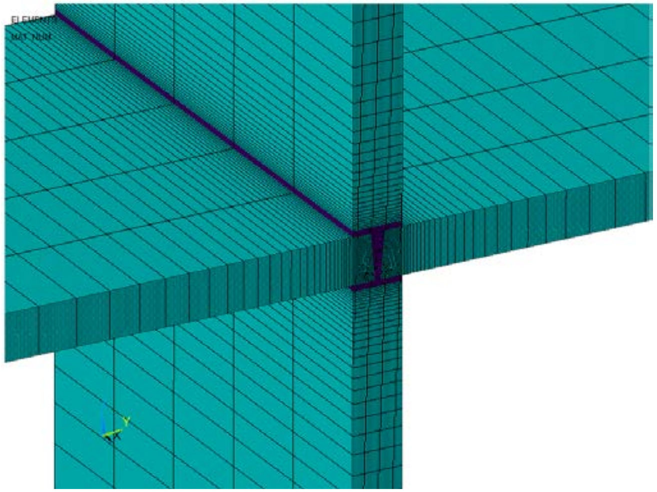


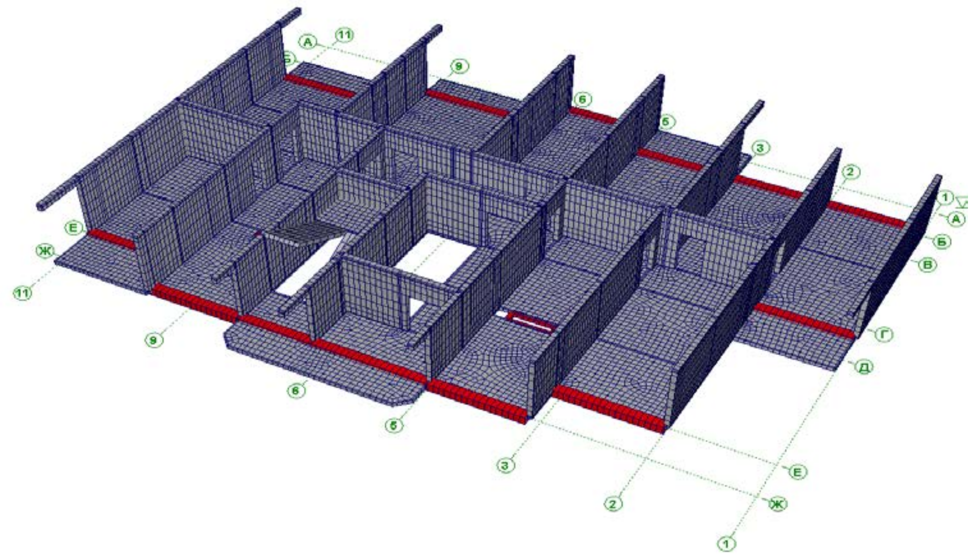
Isometric views of finite element model of temperature block from 4 modules



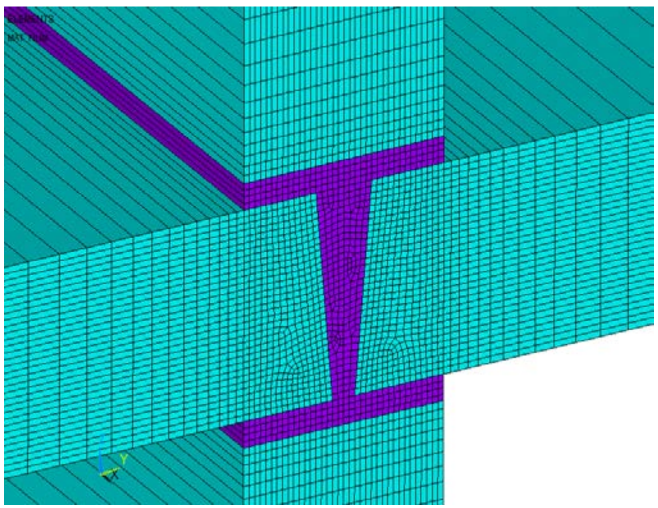
SAMPLES OF NUMERICAL MODELING

Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

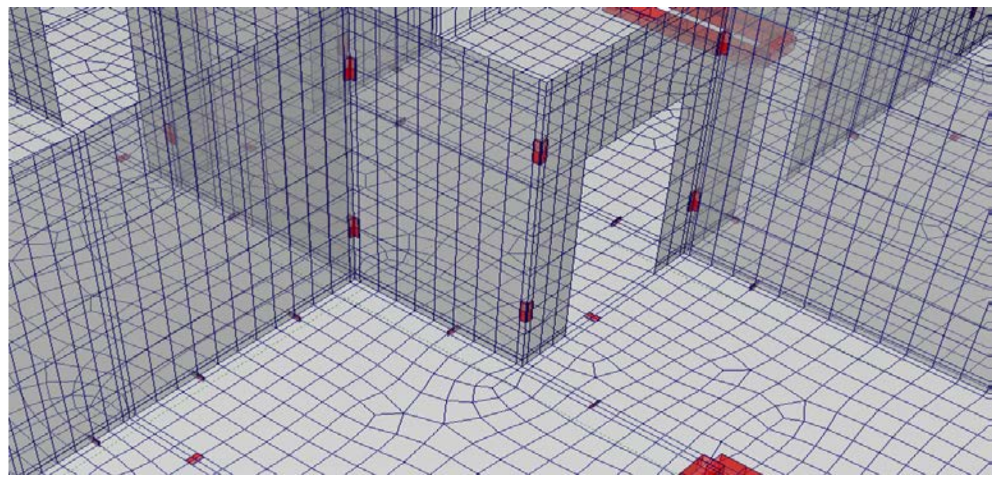




Finite element model of module И-155СП-У11113Нл. Typical floor



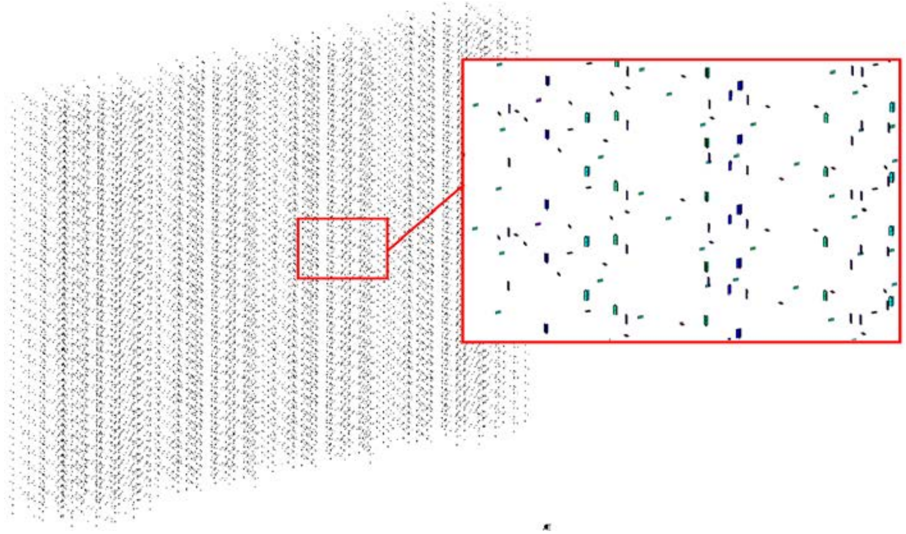
Three-dimensional finite element model of joint fragment (Purple color - contact joint)



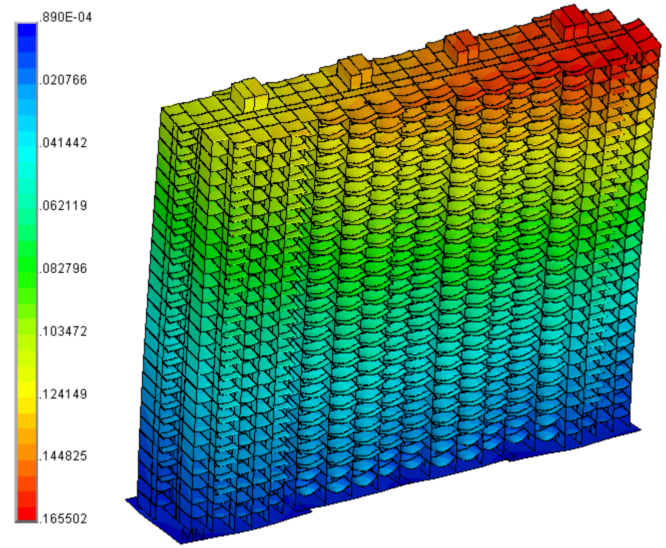
Embedded part s in finite element model

SAMPLES OF NUMERICAL MODELING

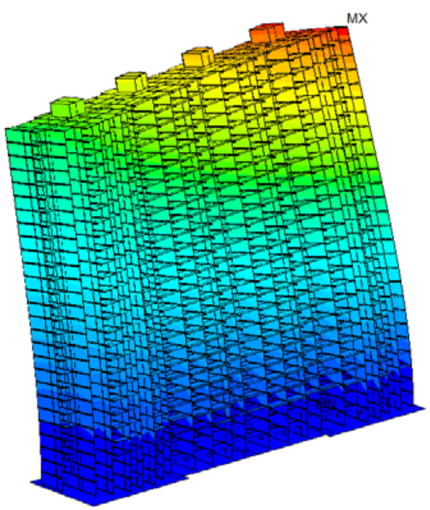
Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

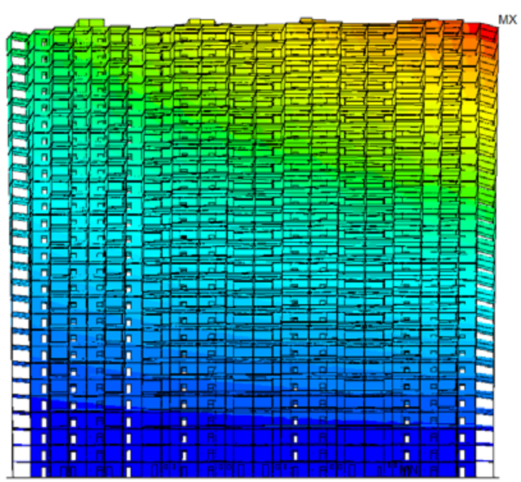


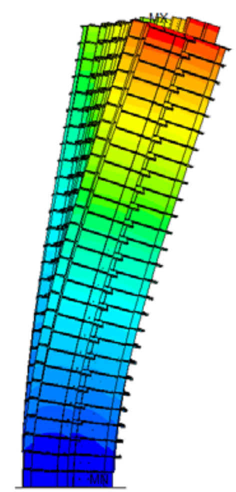
Finite element model of embedded parts (total number – 29 184) of temperature block from four modules

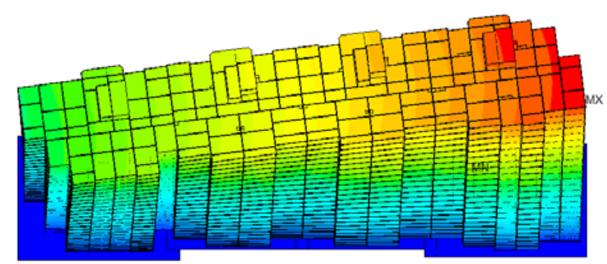


Isofields of total displacements (m) caused by design loads and wind loads from the axes 10-1. Isometric view.









Finite element model of module. Mode shapes, $f_1 = 0.611$ Гц

SAMPLES OF NUMERICAL MODELING

Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

The design variant of reinforcement for each item of the floor slab panels of the crawl space.
Module И-155СП-Р111111

No.	Description	Design variant			
		Top reinforcement, sm^2/m		Bottom reinforcement, sm^2/m	
		Along X	Along Y	По X	По Y
1	РТ 30.51l / РТ 30.51р	**8,70**	**6,27**	**8,56**	**3,67**
2	РТ 27.51l / РТ 27.51р	**13,86**	**9,40**	**8,73**	**4,69**
3	РТ 21.53l / РТ 21.53р	**16,66**	**10,56**	**9,81**	**4,21**
4	РТ 18.36l / РТ 18.38р	**3,51**	**1,90**	**5,81**	**1,15**
5	РТ 18.33l / РТ 18.33р	**4,12 (2,51)**	**3,50 (3,39)**	**2,24 (3,93)**	**1,46 (4,50)**
6	РТ 27.39l / РТ 27.38р	**8,01 (2,51)**	**5,65 (3,45)**	**5,28 (3,93)**	**2,82 (4,87)**
7	РТ 30.31l / РТ 30.33р	**3,27 (2,51)**	**3,27 (3,52)**	**3,34 (3,93)**	**2,00 (4,94)**
8	РТ41.31-1 / РТ 42.33-3	**6,74**	**4,63**	**6,38**	**3,89**
9	РТ 20.66	**2,98 (2,51)**	**2,21 (4,34)**	**1,71 (3,93)**	**0,74 (5,76)**
10	РТ 48.18	**16,79 (2,51)**	**8,99 (6,93)**	**21,0 (3,93)**	**6,11 (8,35)**
11	РТ 19.17 / РТ 18.17	**15,80 (2,51)**	**8,25 (3,41)**	**19,26 (3,93)**	**6,22 (4,83)**

The values of design reinforcement are given in parentheses (shortage, excess и practical closeness)

SAMPLES OF NUMERICAL MODELING

Refined analysis of stress-strain state, strength and stability of single sections and multi-sectional temperature module of the 25-storey panel apartment house (SCAD, ANSYS)

Values of coefficient of exhaustion of load-bearing capacity of embedded parts

	Embedded parts	Welds
	with a ***lower value*** of the modulus of elasticity of the contact weld	with a ***reduced and (initial)*** value of the modulus of elasticity of the contact weld
Module I-155SP-R111111		
P-1	0,99	***1,60 (0,34)***
P-2	0,84	0,11
P-3	0,43	0,04
P-4	0,12	0,06
P-5	0,69	0,33
P-6	0,16	0,04
S-1	0,35	0,29
S-2	0,51	0,45
S-3	0,26	0,22
S-4	0,36	0,85
S-12	0,14	0,20
Module I-155SP-U11113Nl		
P-1	0,16	***2,95 (0,43)***
P-2	0,19	0,05
P-3	0,16	0,04
P-4	0,16	0,07
P-5	0,18	0,27
P-6	0,16	0,02
S-1	0,12	0,04
S-2	0,07	0,75
S-3	0,08	0,22
S-4	0,17	0,51
S-12	0,07	0,33

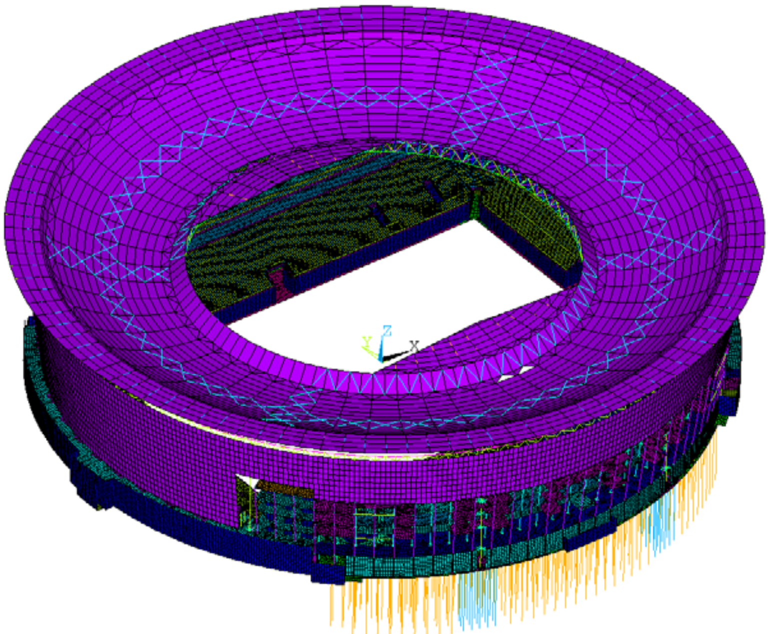
	Embedded parts	Welds
	with a ***lower value*** of the modulus of elasticity of the contact weld	with a ***reduced and (initial)*** value of the modulus of elasticity of the contact weld
Module I-155SP-U31111N		
P-1	0,16	***2,95 (0,43)***
P-2	0,19	0,05
P-3	0,16	0,04
P-4	0,16	0,07
P-5	0,18	0,27
P-6	0,16	0,02
S-1	0,12	0,04
S-2	0,07	0,75
S-3	0,08	0,22
S-4	0,17	0,51
S-12	0,07	0,33
Module I-155SP-U2113Vl		
P-1	0,12	***1,4 (0,29)***
P-2	0,16	0,04
P-3	0,12	0,01
P-4	0,20	0,08
P-5	0,23	0,28
P-6	0,12	0,03
S-1	0,17	0,34
S-2	0,08	***1,56 (0,06)***
S-3	0,16	0,62
S-4	0,15	0,64
S-12	0,05	0,27

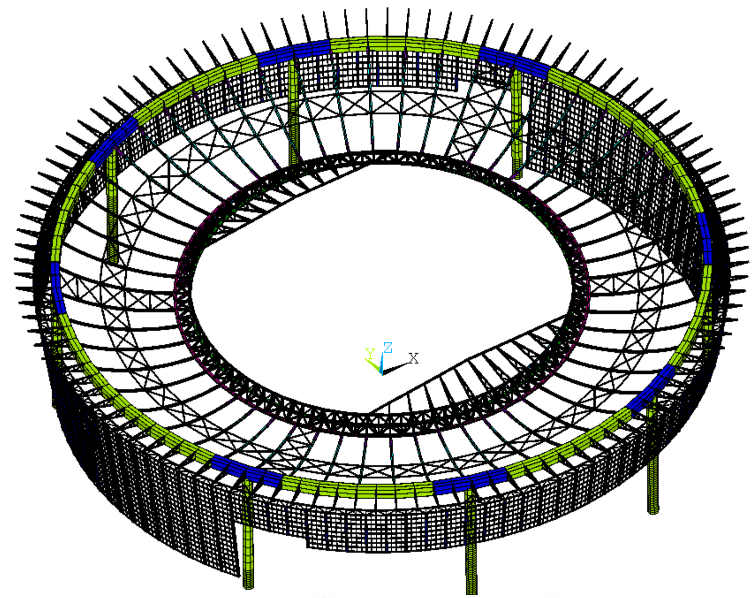
SAMPLES OF NUMERICAL MODELING

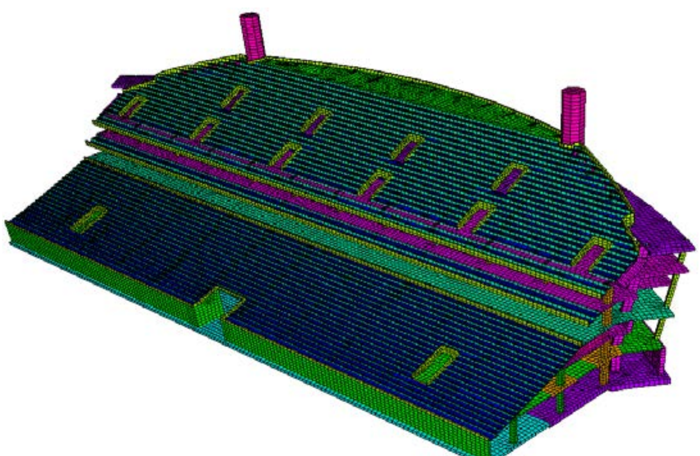
Analysis of stress-strain state, strength and stability of load-bearing structures of football stadiums of the World Cup 2018 (ANSYS)

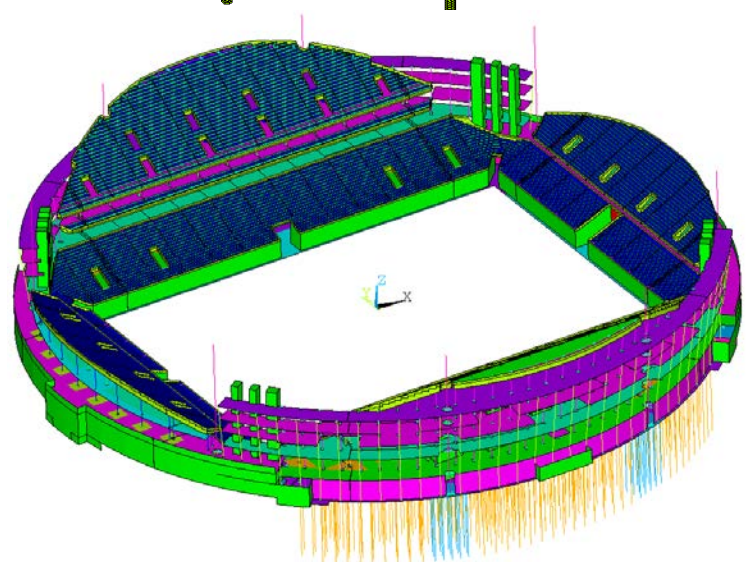
SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of football stadiums of the World Cup 2018 (ANSYS)



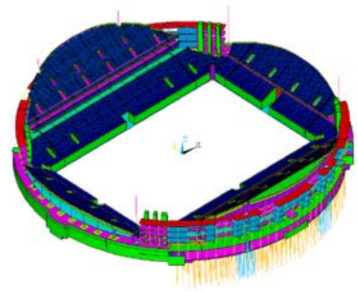
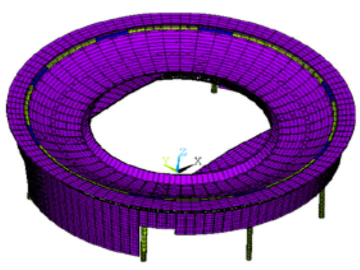
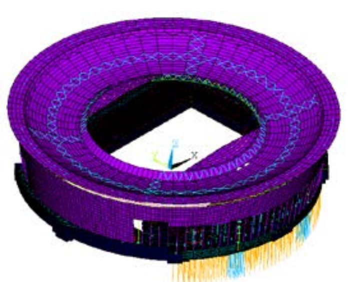






SAMPLES OF NUMERICAL MODELING

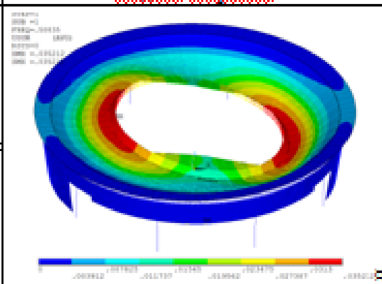
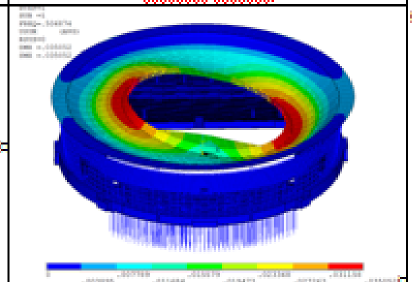
Analysis of stress-strain state, strength and stability of load-bearing structures of football stadiums of the World Cup 2018 (ANSYS)

No.	Finite element models of system / subsystem	Visualization	Number of nodes	Number of elements	Types of finite elements	File name
1	“foundation – reinforced concrete structures of stadium bowl”		*275 437*	*329 204*	SHELL181 BEAM188 MPC184 SURF154 COMBIN14	*EKB_bowl.db*
2	“steel structures of roof”		*37 660*	*21 662*	BEAM188 MPC184 SURF154 COMBIN14	*EKB_roof.db*
3	“foundation – reinforced concrete structures of stadium bowl – steel structures of roof”		*312 636*	*350 382*	SHELL181 BEAM188 MPC184 SURF154 COMBIN14	*EKB_all.db*

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of football stadiums of the World Cup 2018 (ANSYS)

Results of verification of finite element models

	Модель покрытия		Полная модель
1		1	
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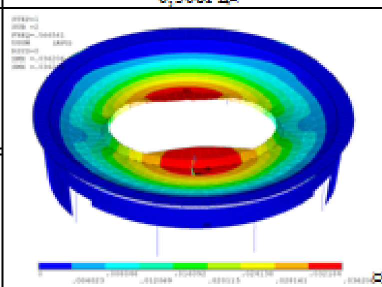
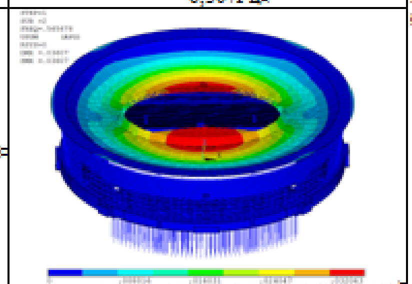
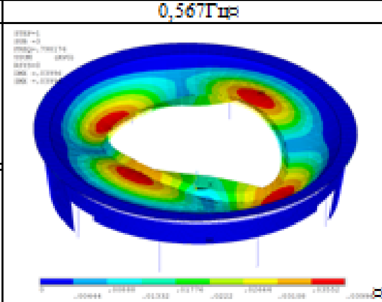
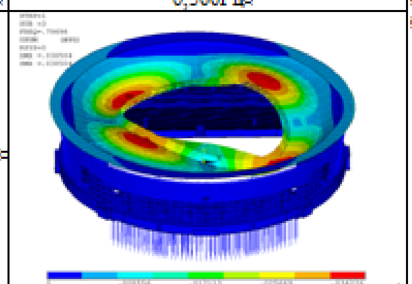
2		2	
	0,567Гц		0,566Гц
3		3	
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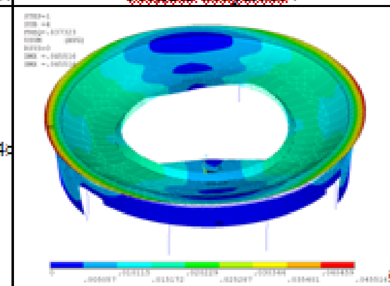
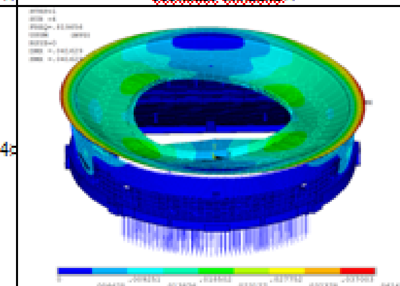
	Модель покрытия		Полная модель
4		4	
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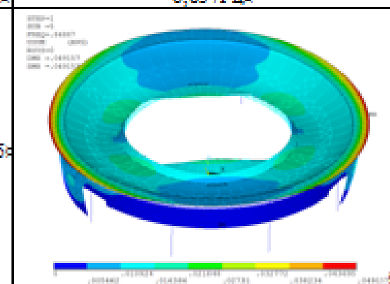
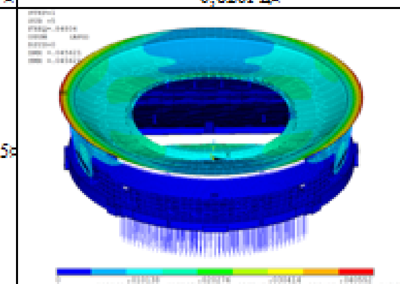
5		5	
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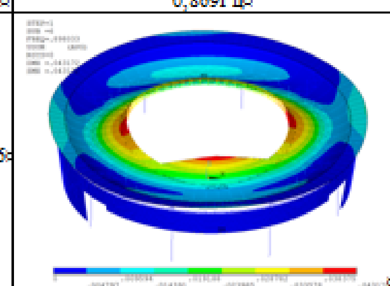
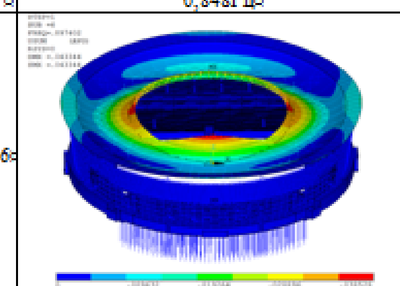
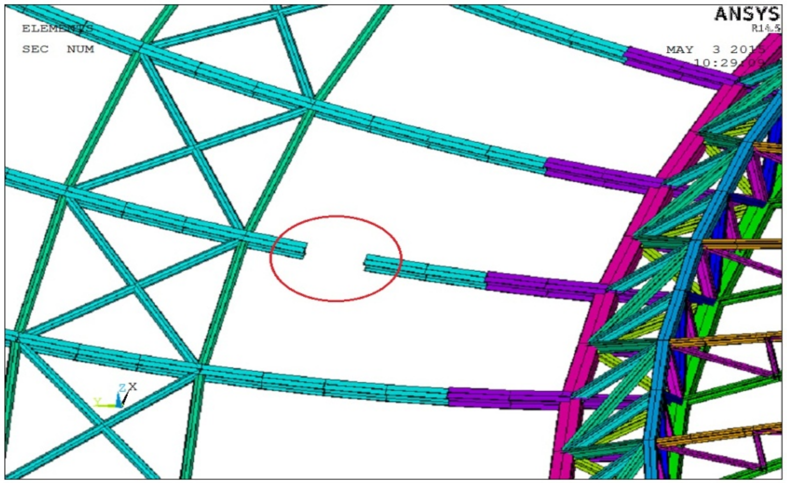
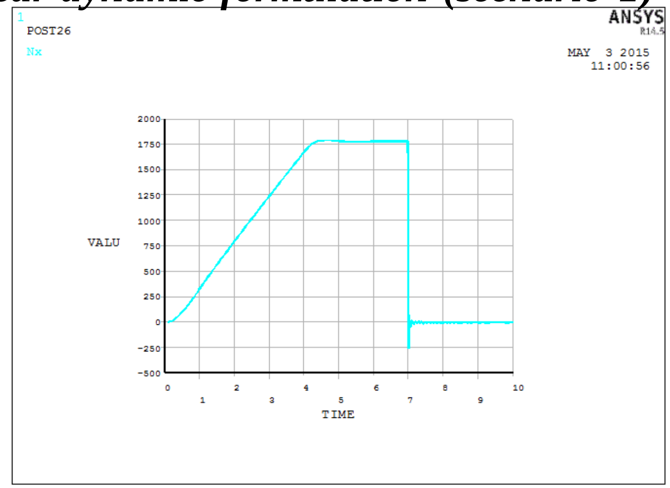
6		6	
	0,898Гц		0,897Гц

SAMPLES OF NUMERICAL MODELLING

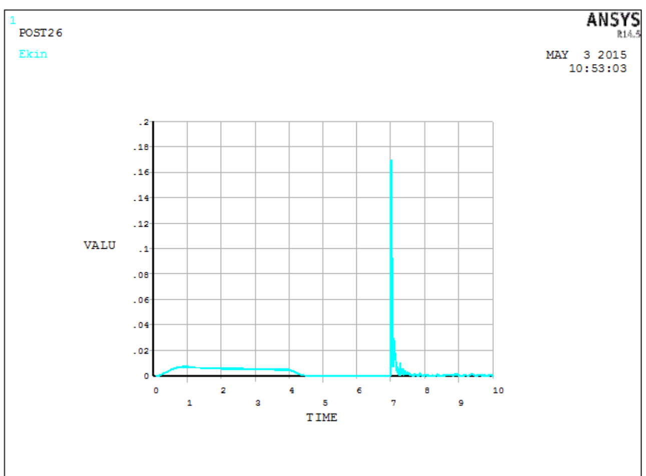
Analysis of stress-strain state, strength and stability of load-bearing structures of football stadiums of the World Cup 2018 (ANSYS)

Progressive collapse analysis with the use of nonlinear dynamic formulation (scenario 1)

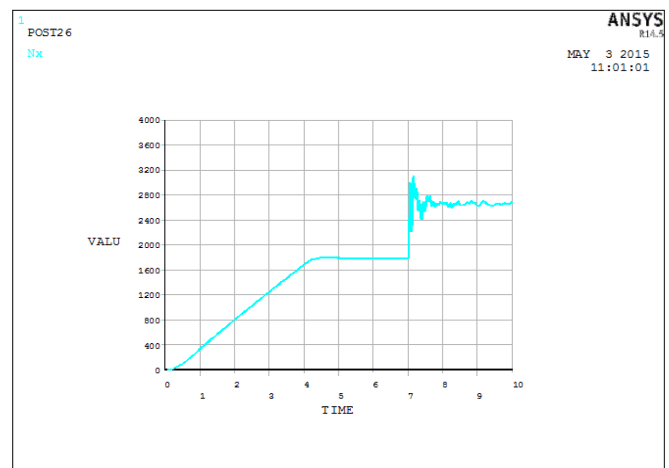




Change in longitudinal force in the damaged suspension, kN



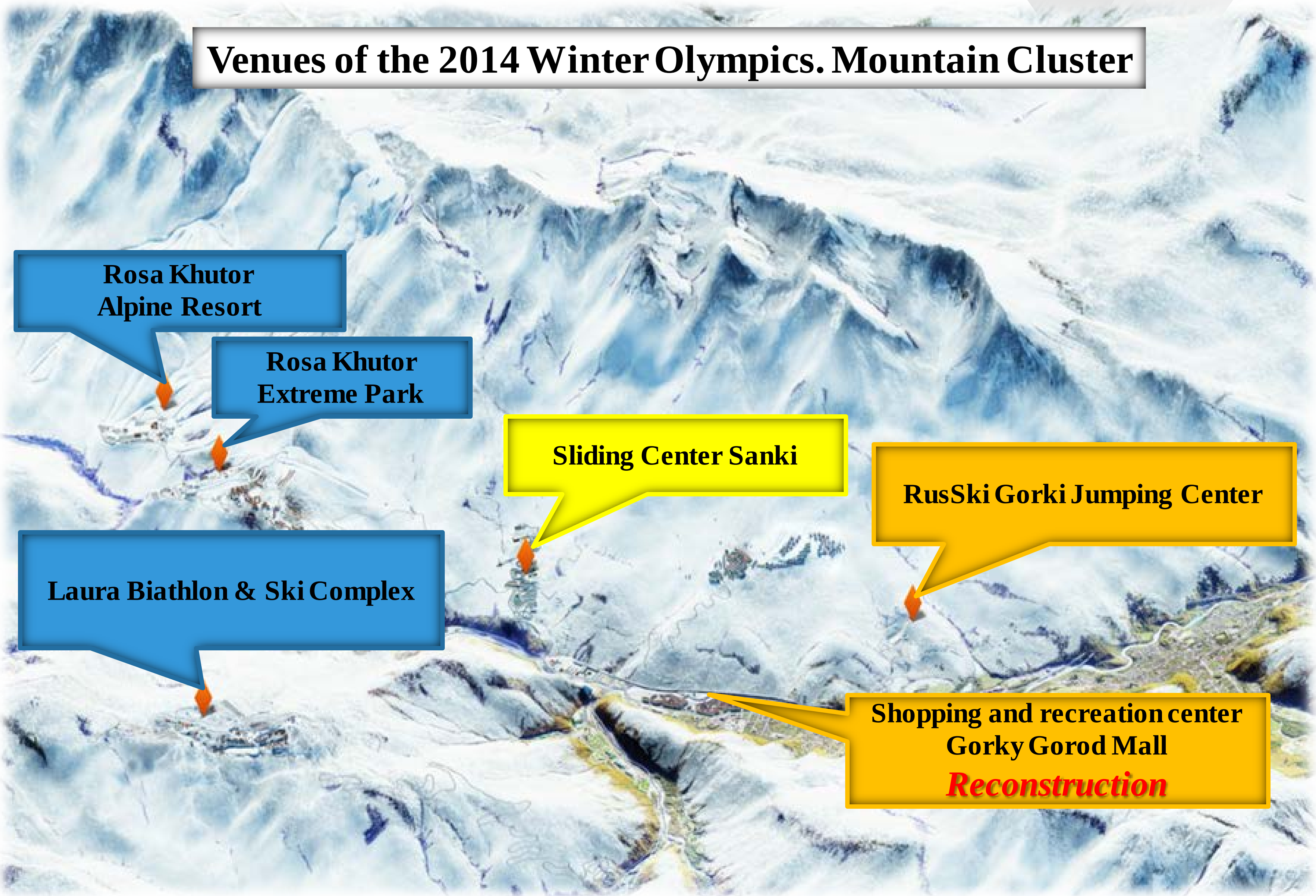
The kinetic energy at the site
In the area of the removed element, kJ



Change in longitudinal force in the adjacent suspension, kN

SAMPLES OF NUMERICAL MODELING

SAMPLES OF NUMERICAL MODELING



SAMPLES OF NUMERICAL MODELING

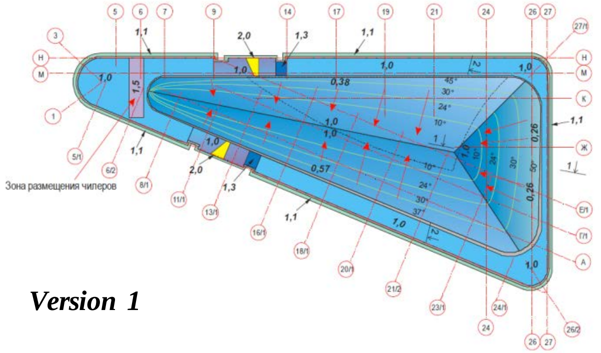
Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

Loads and coefficients of design load combinations

No.	Description	Load combination: The first main load combination	Load combination: The second main load combination	Load combination: Special	No.	Description	Load combination: The first main load combination	Load combination: The second main load combination	Load combination: Special
1	Dead load from structures other than foundations	1.0	1.0	0.9	17	Seismic load along Y (the reinforced concrete roof, snow chart 3)	0.0	0.0	1.0
2	Permanently acting load	1.0	1.0	0.9	18	Seismic load along Z (the reinforced concrete roof, snow chart 3)	0.0	0.0	1.0
3	Dead load from base slab + permanently acting load	1.0	1.0	0.0	19	Dead load from roof structures	1.0	1.0	0.9
4	Short duration floor load	1.0	0.9	0.5	20	Permanently acting roof load	1.0	1.0	0.9
5	Short duration load on base slab	1.0	0.9	0.0	21	Snow roof load (version 1)	1.0	0.9	0.5
6	Load from water in the pool	1.0	0.95	0.8	22	Snow roof load (version 2)	1.0	0.9	0.5
7	Snow load on the reinforced concrete cover (version 1)	1.0	0.9	0.5	23	Snow roof load (version 3)	1.0	0.9	0.5
8	Snow load on the reinforced concrete cover (version 2)	1.0	0.9	0.5	24	Wind load X1	1.0	0.9	0.0
9	Load on the basement walls	1.0	1.0	0.9	25	Wind load X2	1.0	0.9	0.0
10	Seismic load along X (the reinforced concrete roof, snow chart 1)	0.0	0.0	1.0	26	Wind load Y1	1.0	0.9	0.0
11	Seismic load along Y (the reinforced concrete roof, snow chart 1)	0.0	0.0	1.0	27	Wind load Y2	1.0	0.9	0.0
12	Seismic load along Z (the reinforced concrete roof, snow chart 1)	0.0	0.0	1.0	28	Temperature (negative drop / long term component)	1.0	0.95	0.0
13	Seismic load along X (the reinforced concrete roof, snow chart 2)	0.0	0.0	1.0	29	Temperature (negative drop / integrated component)	1.0	0.9	0.0
14	Seismic load along Y (the reinforced concrete roof, snow chart 2)	0.0	0.0	1.0	30	Temperature (positive drop / long term component)	1.0	0.95	0.0
15	Seismic load along Z (the reinforced concrete roof, snow chart 2)	0.0	0.0	1.0	31	Temperature (positive drop / long term component)	1.0	0.9	0.0
16	Seismic load along X (the reinforced concrete roof, snow chart 3)	0.0	0.0	1.0					

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)



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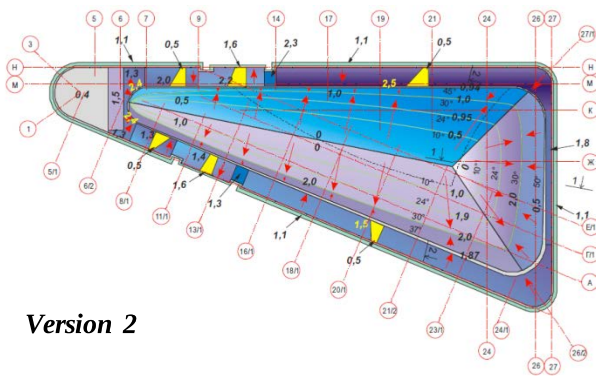
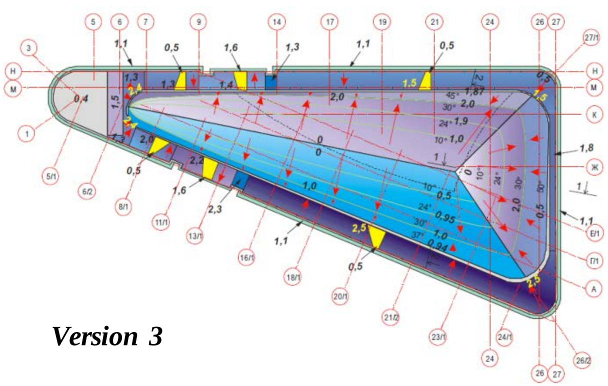
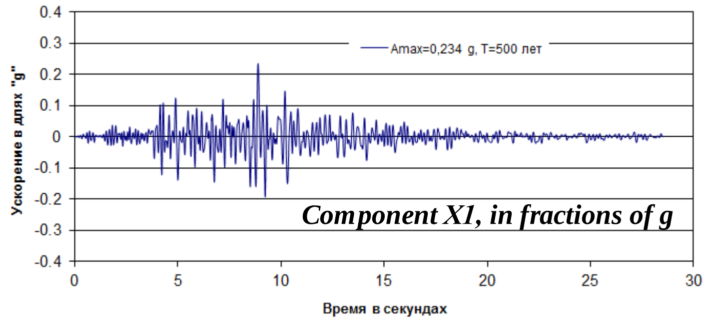


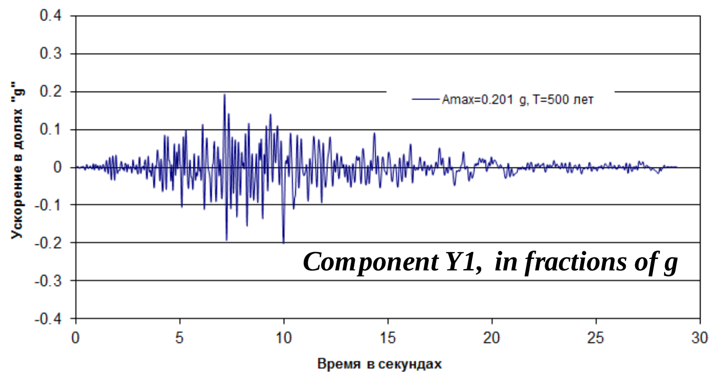
Version 2

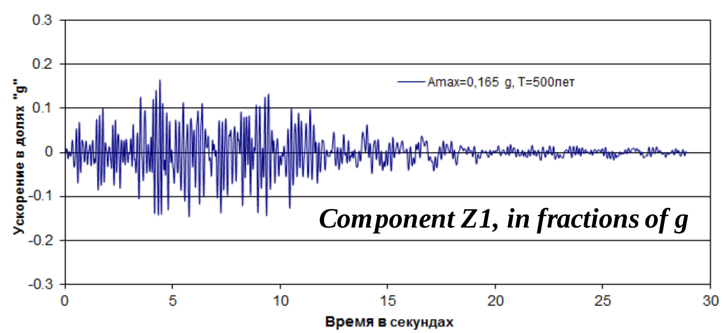


Version 3

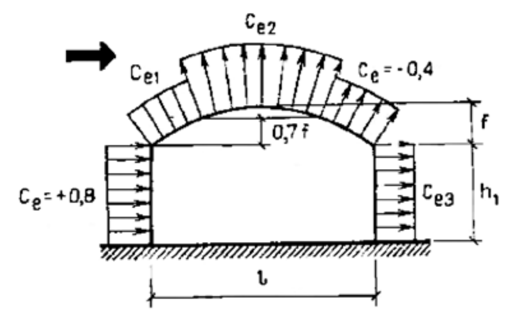
Snow load chart



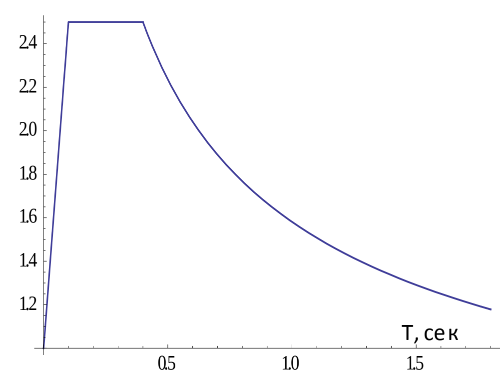




Design accelerogram



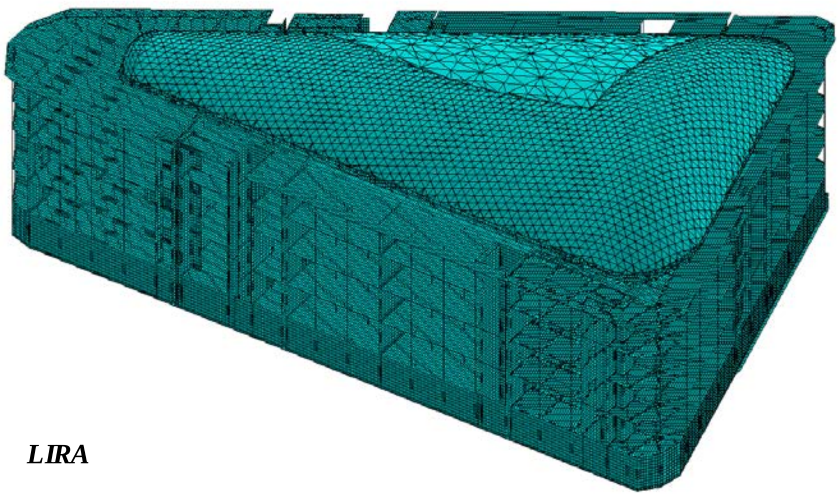
Wind load chart



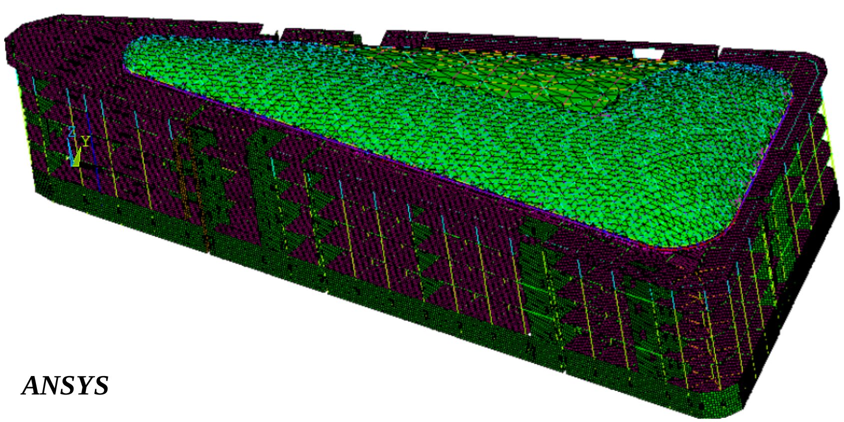
Plot of dynamic response factor β (plot dependence, sec) in accordance with deign codes

SAMPLES OF NUMERICAL MODELLING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)



LIRA



ANSYS

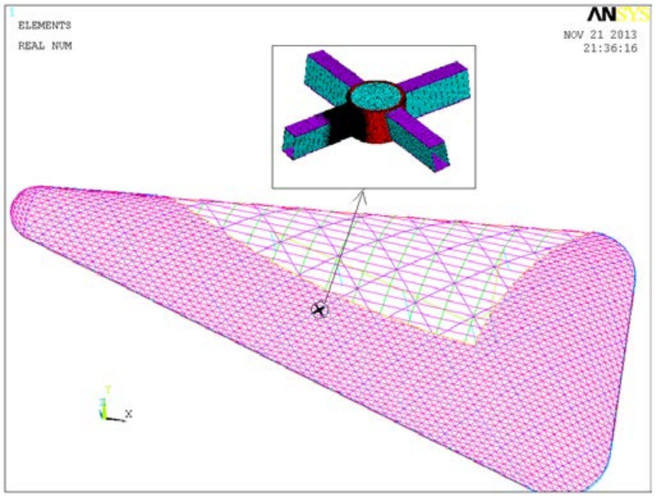
Integrated shell-bar finite element model of system "foundation – reinforced concrete structures – elastomers – roof"

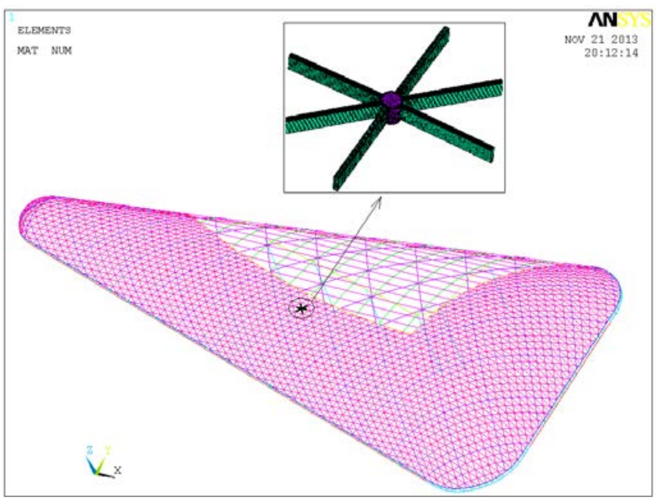
Description and computational parameters of finite element models

No.	Description	Number of finite elements	Number of nodes	Nonlinearity, dynamics
1	Model 1 "integrated" (Lira)	230 177	191 247	–
2	Model 2 "integrated" (ANSYS)	499 141	183 889	Accelerograms, integration of the process of deformation in time
3	Model 3 of the roof (Lira)	11 004	2 730	–
4	Model 3 of the roof (ANSYS)	208 392	220 438	Geometrical and physical nonlinearities
5	Models 5/1 – 5/5 of the roof, progressive collapse analysis (ANSYS)	33 998	21 544	Geometrical and physical nonlinearities, integration of the process of deformation in time
6	Model of the joint 6 (ANSYS)	450 000	1 500 000	Geometrical and physical nonlinearities
7	Model of the joint 7 (ANSYS)	260 000	820 000	Geometrical and physical nonlinearities

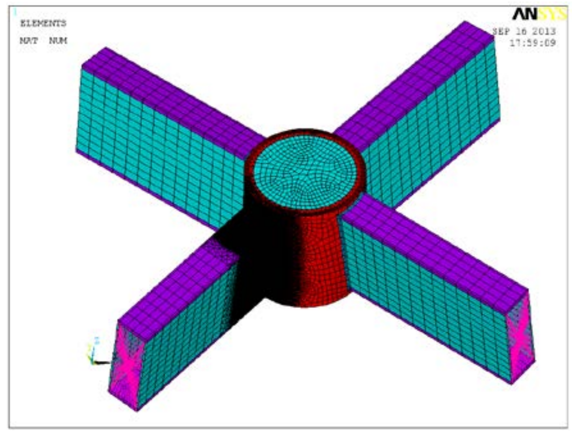
SAMPLES OF NUMERICAL MODELING

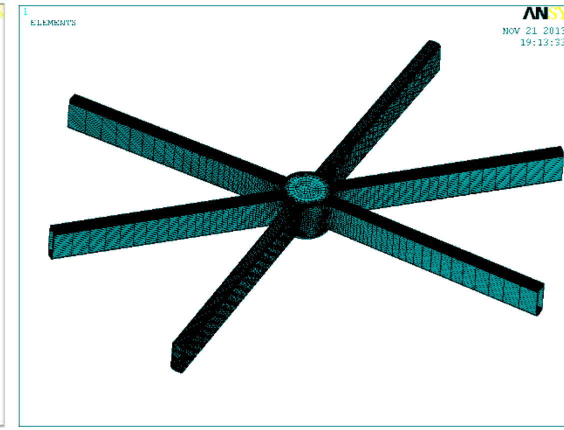
Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)



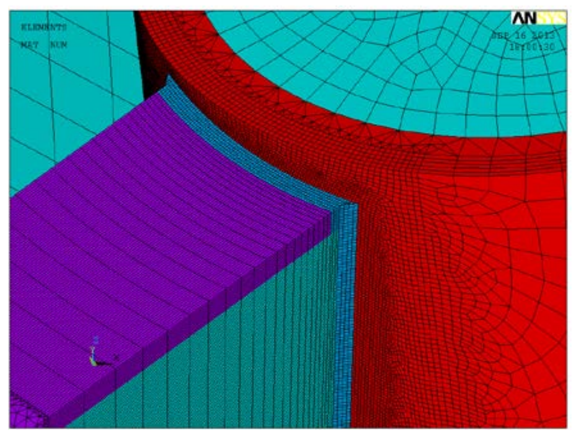


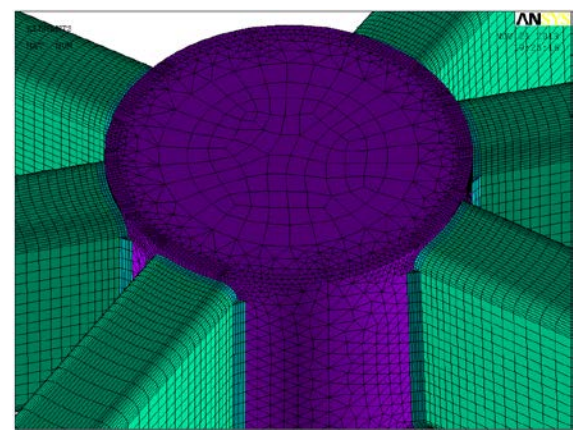
Location of three-dimensional finite element models of large joint (Model 6) and small joint (Model 7) within bar model of roof. General view.
Load elements are not shown





Visualization of materials





Three-dimensional finite element models of large joint (at the left) and small joint (at the right) with detailed mesh

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

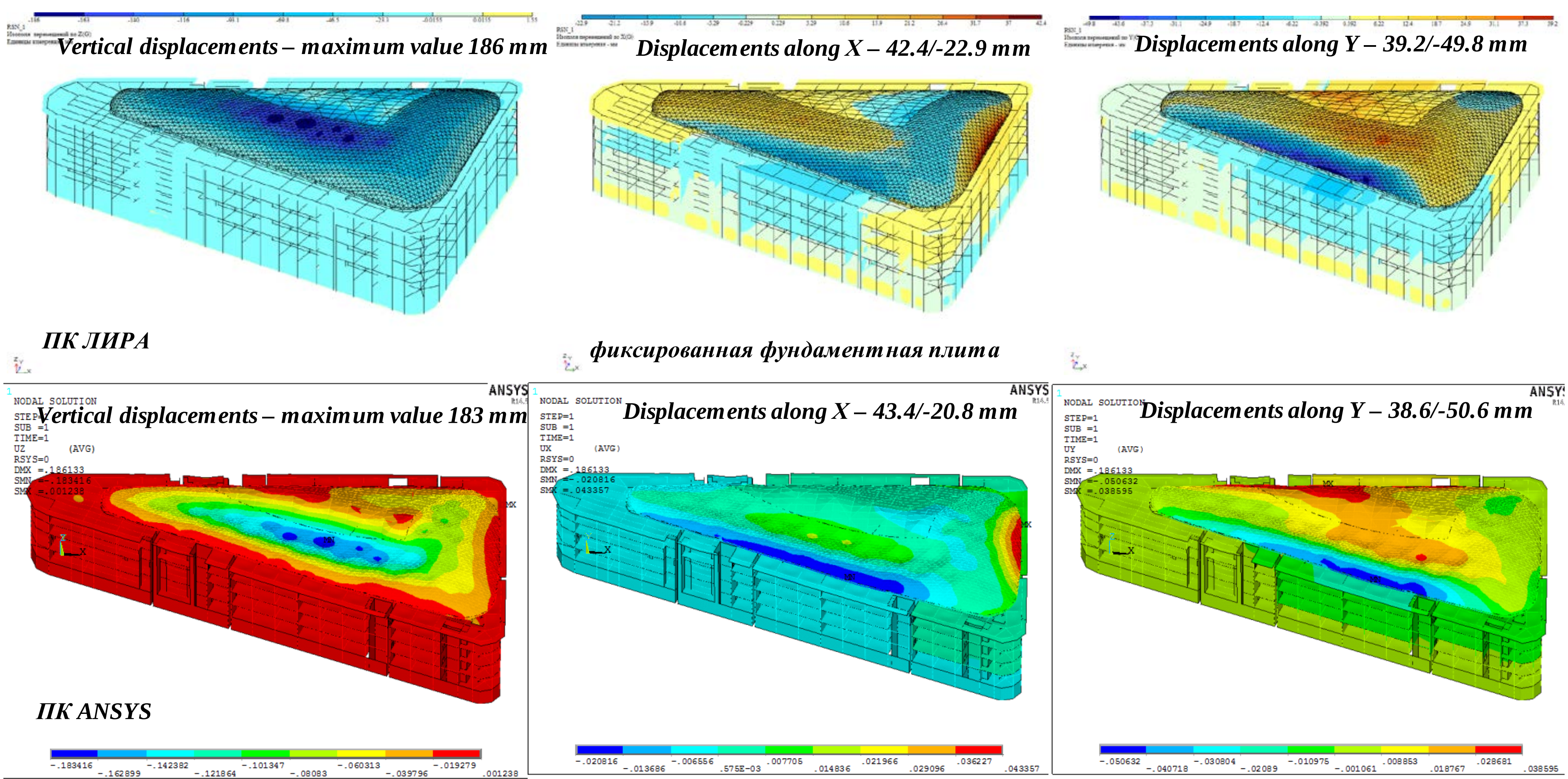
Verification of natural frequencies of finite element models for masses collected from the first combination under Section 4.3

Natural frequencies, Hz						
Number of frequency	Model 1 (LIRA)	Model 2 (ANSYS)	Difference between models 1 and 2	Model 3 (LIRA)	Model 4 (ANSYS)	Model 5 (ANSYS)
1	1.08	1.119	3.56%	1.14	1.198	1.169
2	1.54	1.591	3.29%	1.58	1.673	1.654
3	1.62	1.674	3.34%	1.69	1.781	1.757
4	1.72	1.788	3.93%	1.86	1.946	1.932
5	1.79	1.849	3.27%	1.94	2.037	2.025
6	1.87	2.032	8.65%	2.07	2.174	2.161
7	1.92	2.078	8.25%	2.18	2.256	2.258
8	1.98	2.124	7.27%	2.27	2.338	2.327
9	2.02	2.152	6.53%	2.33	2.417	2.412
10	2.04	2.189	7.32%	2.46	2.576	2.574
Masses						
Total weight / loadnjy	76820.27 t (without foundation)	76871 t (without foundation)	0.06%	3743.8 t	3714.0 t	3734.5 t

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

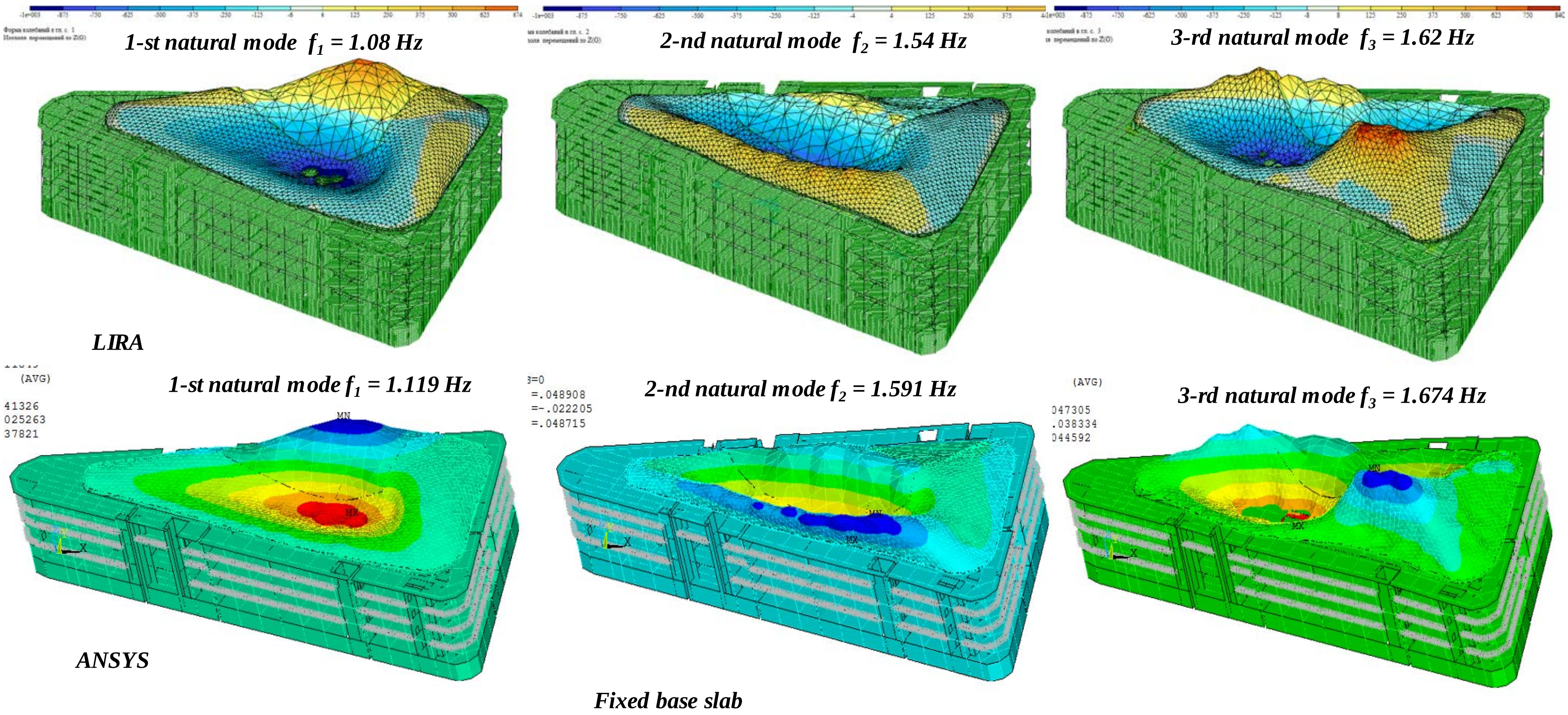
Visualization of displacements for models 1 (LIRA) and 2 (ANSYS)



SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

Visualization of natural modes for models 1 (LIRA) and 2 (ANSYS)

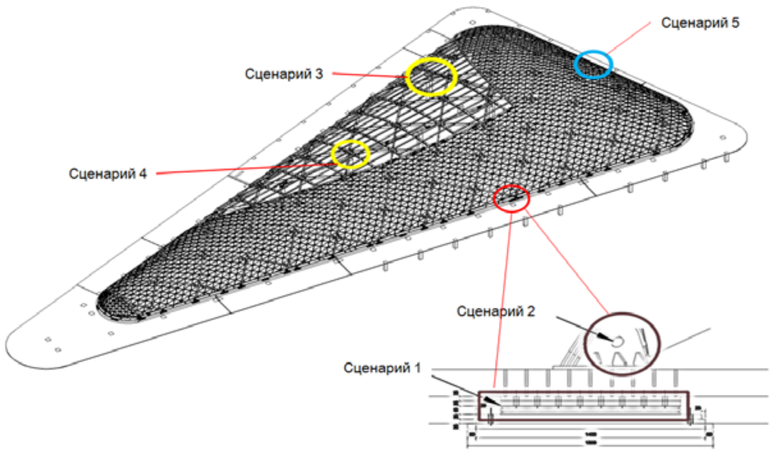


SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

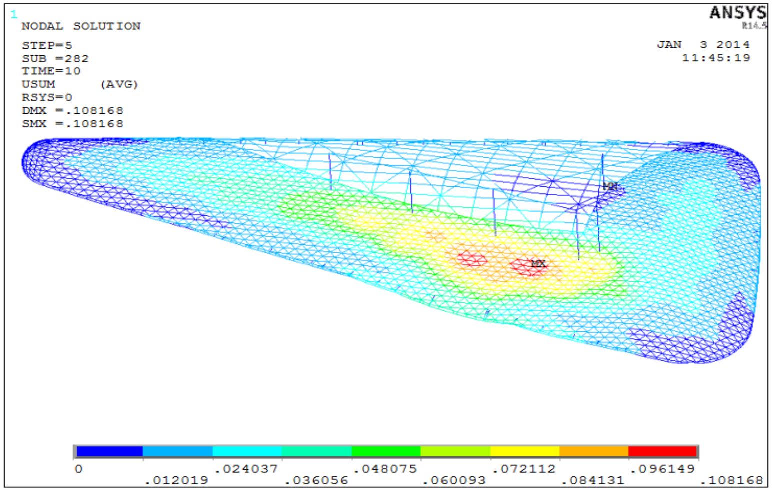
Stability of roof structures against progressive collapse

Scheme of the location of zones of elements excluded from models

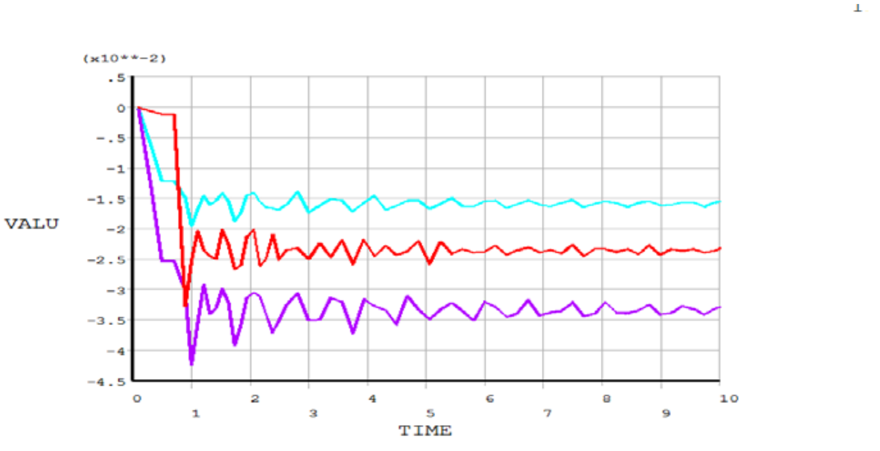


Scenarios under consideration

No.	Scenario
1	Failure of two adjacent blocks of elastomeric bearings
2	Failure of pin joint of arch from the box-shaped profile 200x600 and support contour 600x200
3	The loss of a stable position of reinforced concrete column 800x800, which serves as a support for the roof
4	Destruction of the arch assembly 200x600 in the support zone on the I-beam 600
5	Destruction of the support contour from the elements 600x200



Scenario 1. Total displacements in system, m (maximum value – 0,066 m)

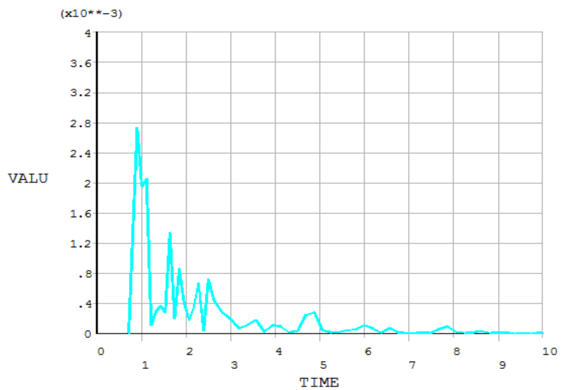


Scenario 1. Plot of displacements of the upper node of adjacent elastomeric block, m

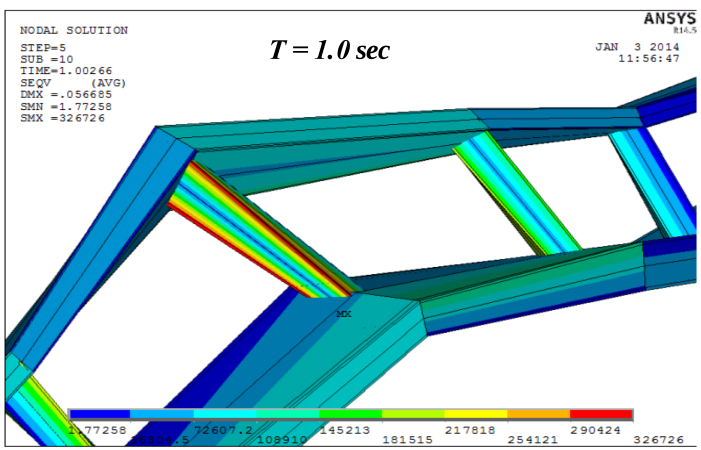
SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)

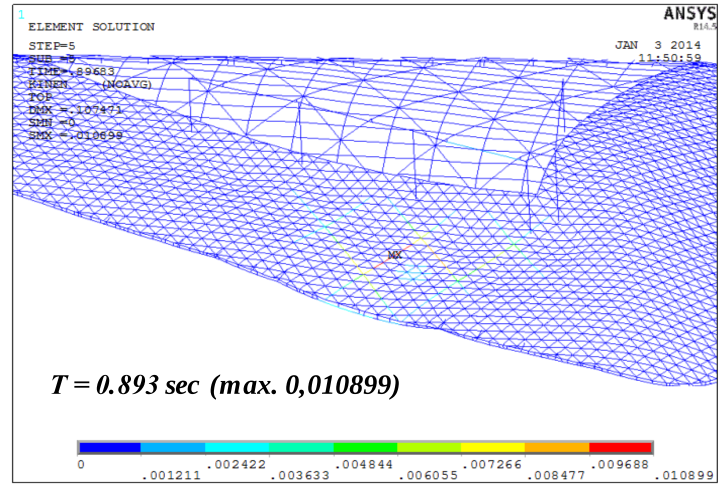
Stability of roof structures against progressive collapse

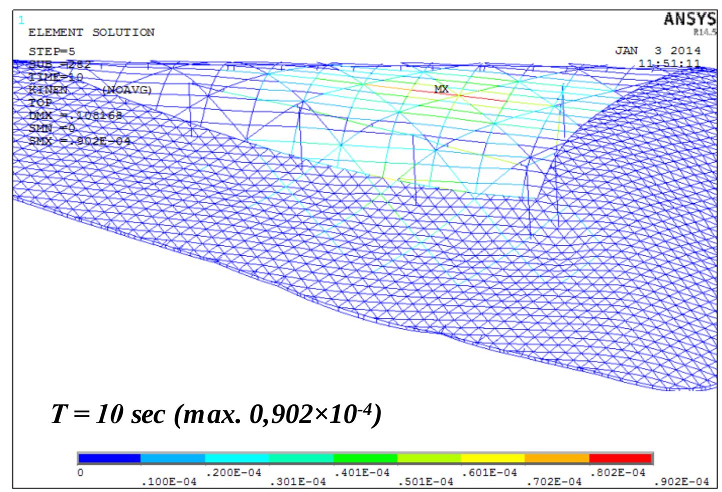


Scenario 1. The plot of the change in the kinetic energy of a neighboring adjacent elastomer node



Scenario 1. Mises equivalent stresses, kPa (max. 326.7 MPa)

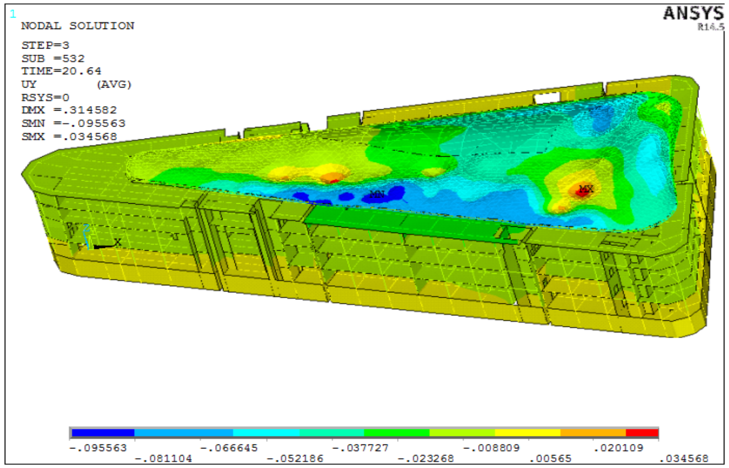




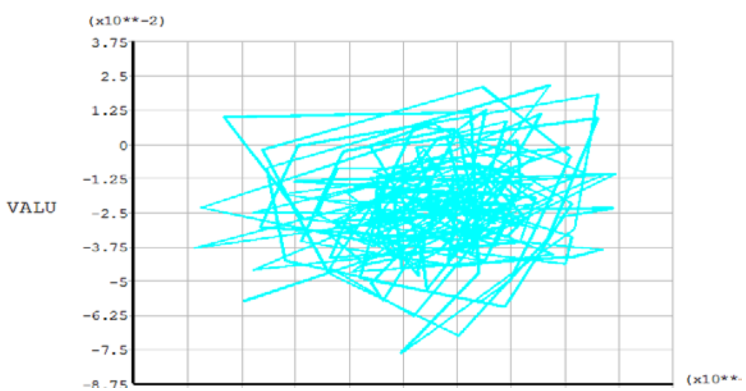
Scenario 1. Kinetic energy by elements for different time points

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Shopping and recreation center Gorky Gorod Mall (ANSYS, LIRA)



Static analysis+Seismic analysis. 1. Total displacements along Y for time point 20.64 s (Maximum modulus of displacements of the elastomer 198210 along Y)



Static analysis+Seismic analysis. 2. Plot of displacements in the XY space of the upper node of elastomer (element 198210) in the process of loading, m (Y is the direction towards the stop)

Results of analysis with allowance for accelerograms for elastomers

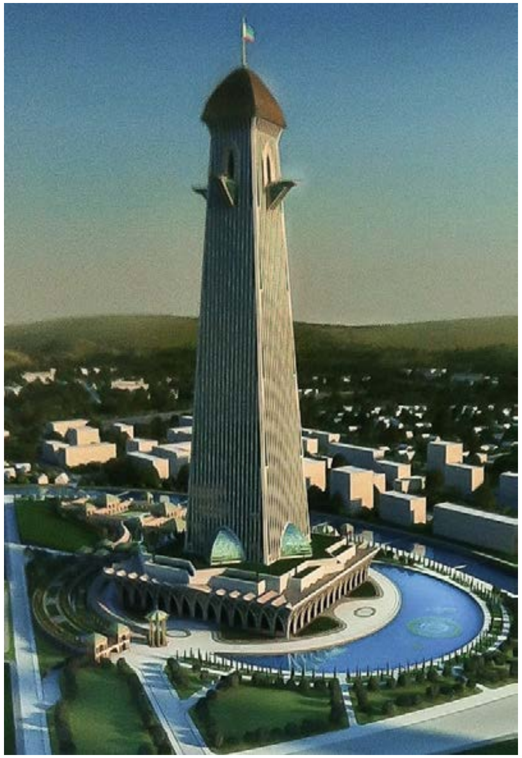
Relative displacements of the upper nodes of elastomer (static analysis + seismic analysis)

Element number	Combination	Xmin, sm	Xmax, sm	Ymin, sm	Ymax, sm
198210	1	-2.72	0.99	-5.51*	1.79
198230	1	-3.73	1.71	-5.6*	1.74
198455	1	-3.02	1.62	-4.48*	0.64
198205	2	-3.26	0.96	-5.92*	1.54
198210	2	-3.44	0.47	-7.62*	2.16
198220	2	-4.69	1.29	-6.24*	1.38
198255	2	-5.1	1.54	-6.34*	0.83
198230	2	-5.99	1.92	-6.33*	0
198235	2	-5.57	2.56	-5.29*	0
198240	2	-5.56	2.59	-5.18*	0
198245	2	-5.44	3.07	-4.94*	0
198250	2	-5.92	3.31	-5.71*	0.18
198255	2	-5.33	2.25	-6.38*	1.77
198260	2	-4.88	2.52	-5.86*	1.8
198295	2	-2.78	6.87*	-3.57	3.88
198300	2	-3.56	7.00*	-3.3	3.96
198305	2	-3.31	6.95*	-3.21	4.01
198295	3	-1.38	2.68*	-4.61	3.83
198300	3	-1.64	7.19*	-4.29	3.86
198305	3	-1.48	6.81*	-4.14	3.83
198350	3	-2.54	2.91	-1.58	5.67*
198355	3	-2.64	2.82	1.52	6.14*
198360	3	-2.65	2.82	1.62	6.21*
198365	3	-2.59	2.69	-1.96	6.86*
198370	3	-2.58	2.62	-1.65	6.27*

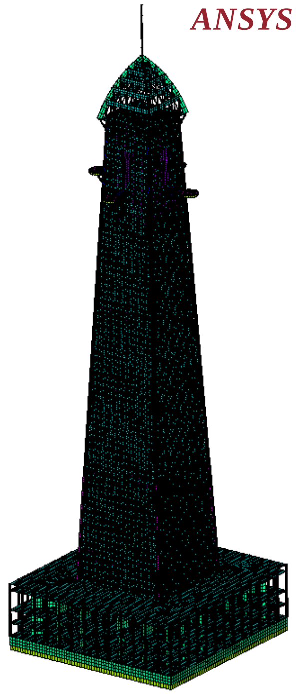
** – the direction towards the stop is marked*

SAMPLES OF NUMERICAL MODELING

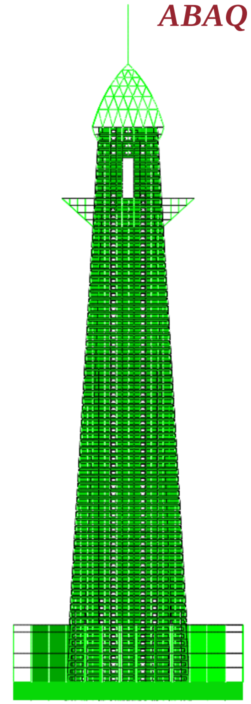
Analysis of stress-strain state and strength of load-bearing structures of the Akhmat tower (Grozny) with allowance for static, seismic and wind loads (ANSYS, ABAQUS)

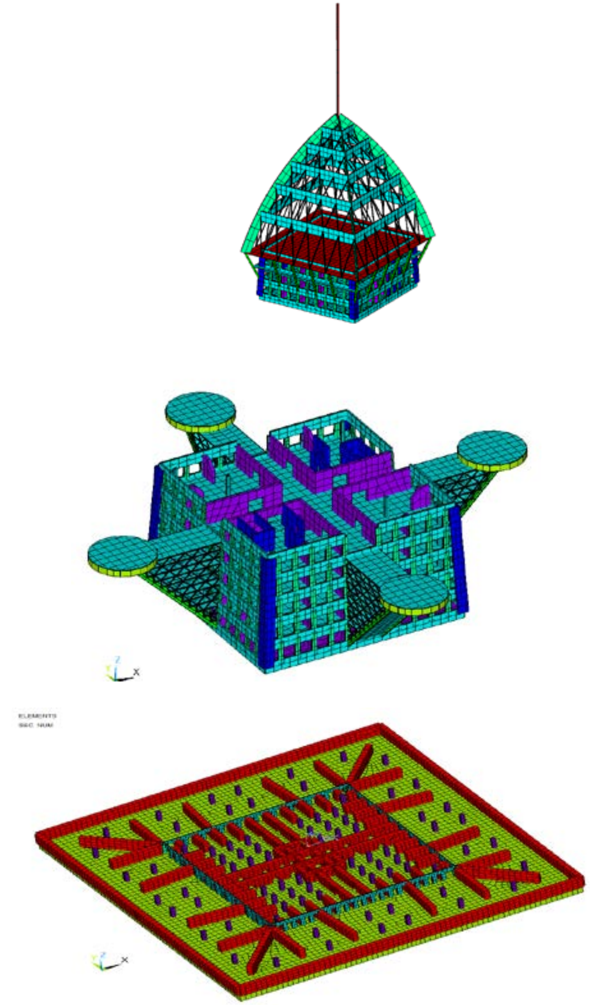


ANSYS

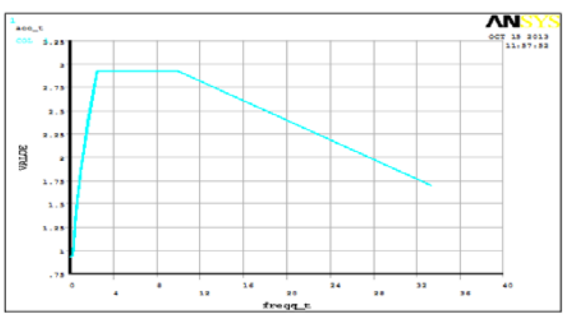


ABAQUS

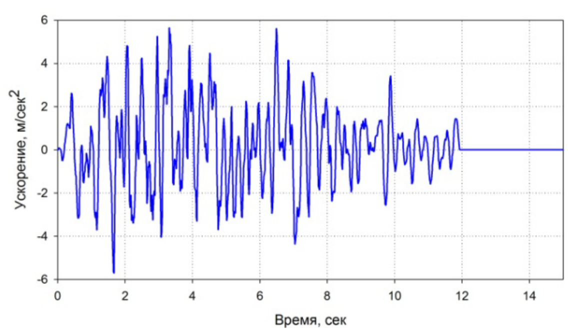




Finite element models of a dome, floors from 65 to 69 with helipads and two floors (with a stylobate part)
ANSYS



Design response spectrum
Accelerations, m/s² - frequencies, Hz



Accelerogram corresponding to maximum design earthquake

SAMPLES OF NUMERICAL MODELING

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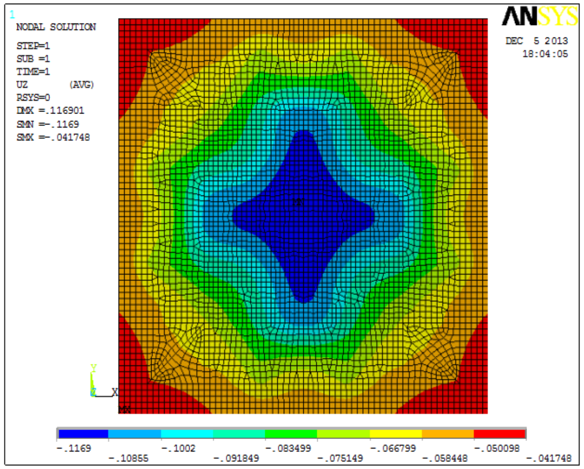
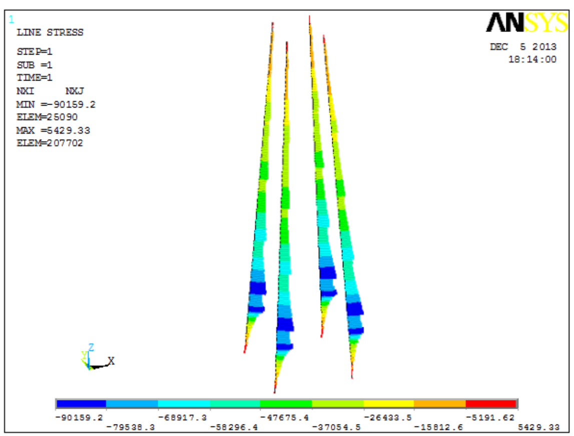
Static analysis

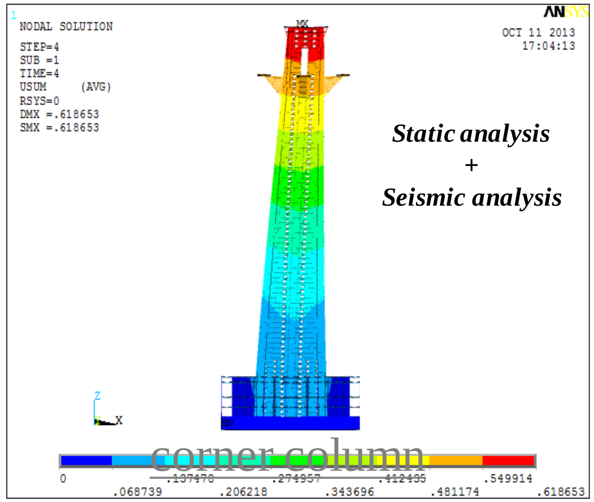


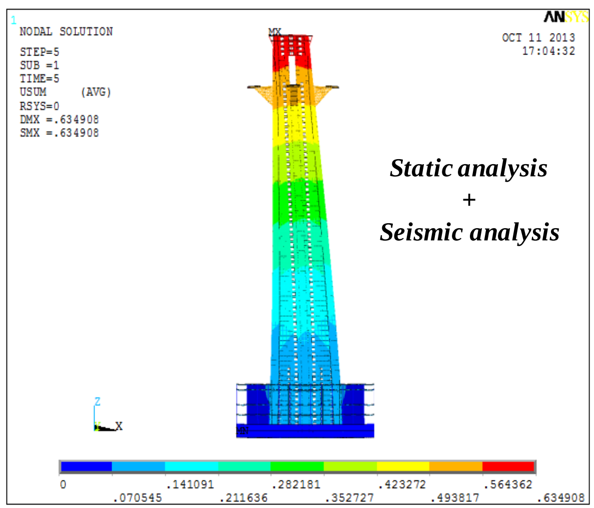
Deflections of the base slab under the main combination of loads, m (maximum value is 0,117 m)



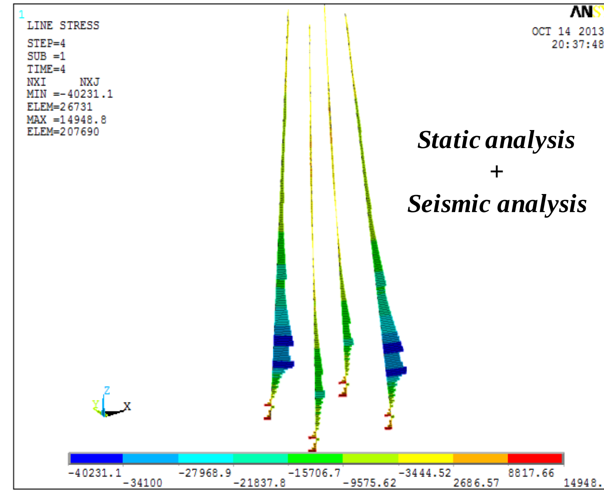
Normal forces in corner columns, kN

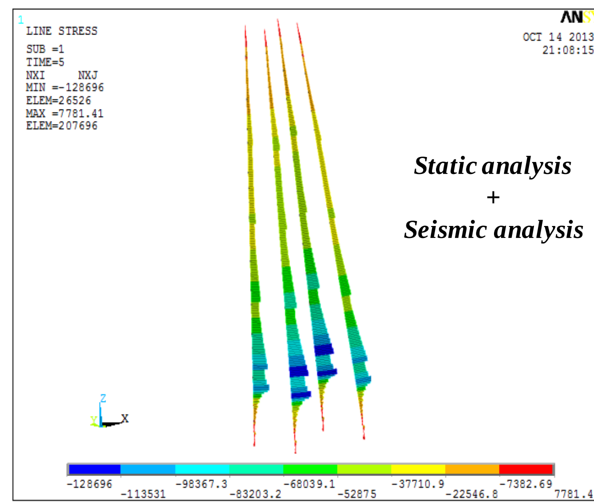
Seismic analysis (8,5 on MSK-64 scale) based on linear spectral theory





Total displacements, m



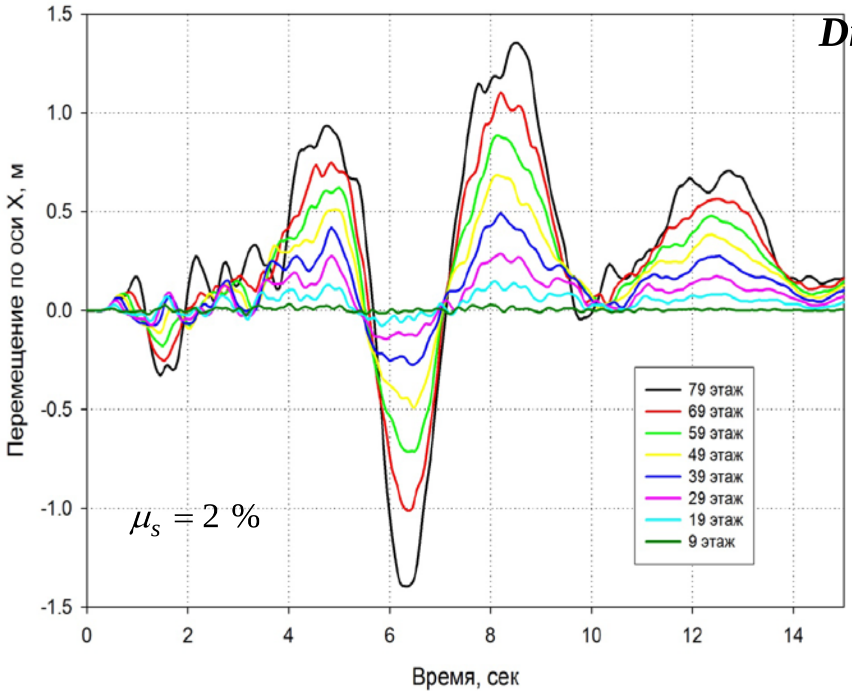


Normal forces in corner columns, kN

SAMPLES OF NUMERICAL MODELING

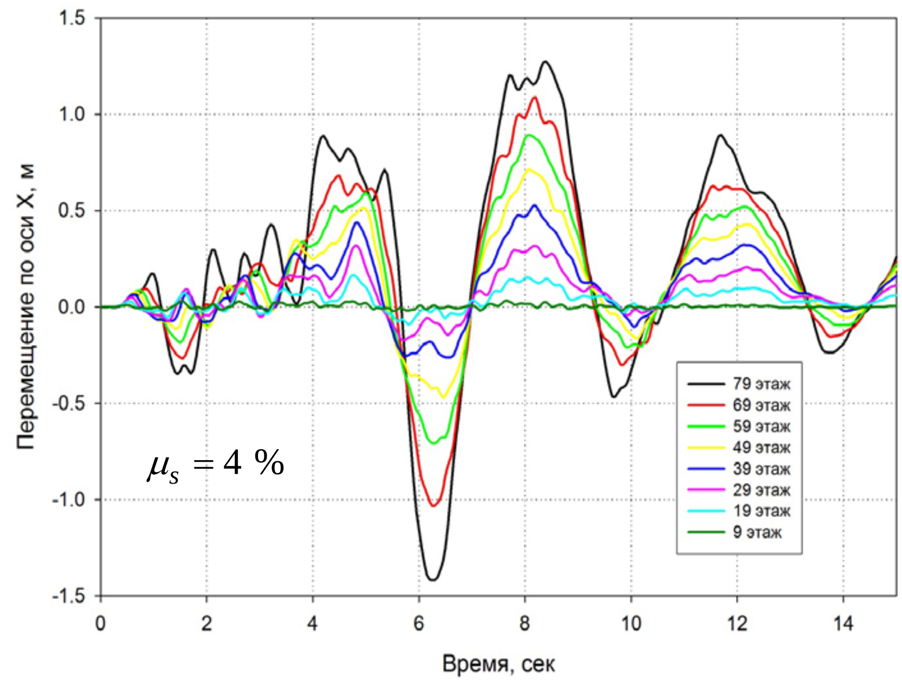
Analysis of stress-strain state and strength of load-bearing structures of the Akhmat tower (Grozny) with allowance for static, seismic and wind loads (ANSYS, ABAQUS)

Direct nonlinear (geometrical and physical nonlinearities) dynamic analysis based on explicit scheme



Displacements of various floors along X caused by maximum design earthquake

Reinforcement ratio of vertical structures μ_s



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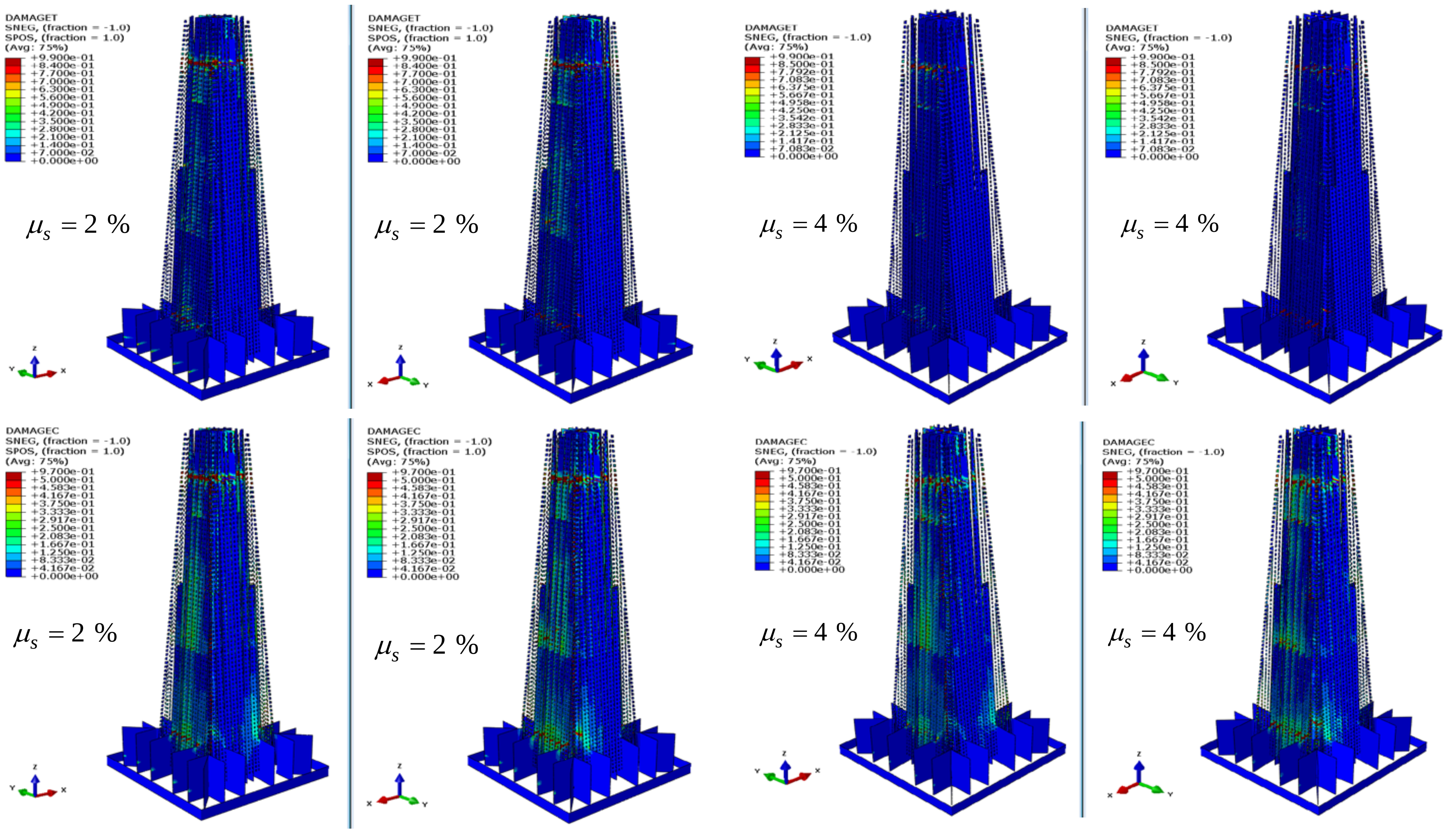
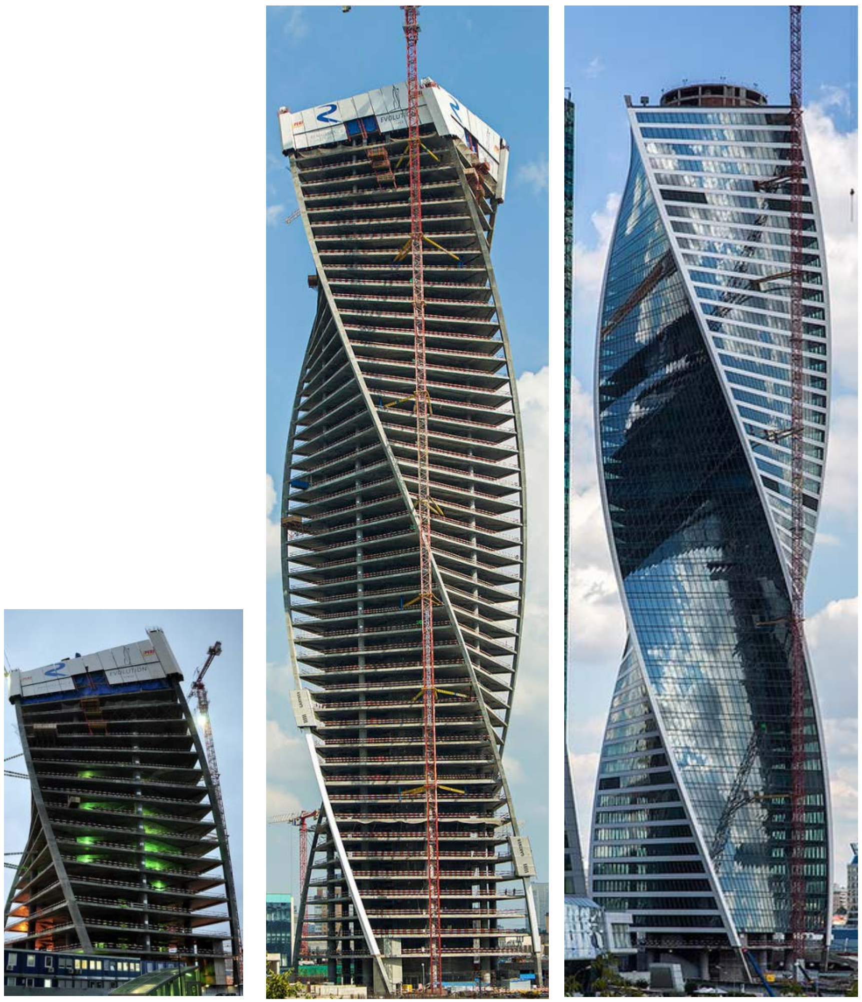


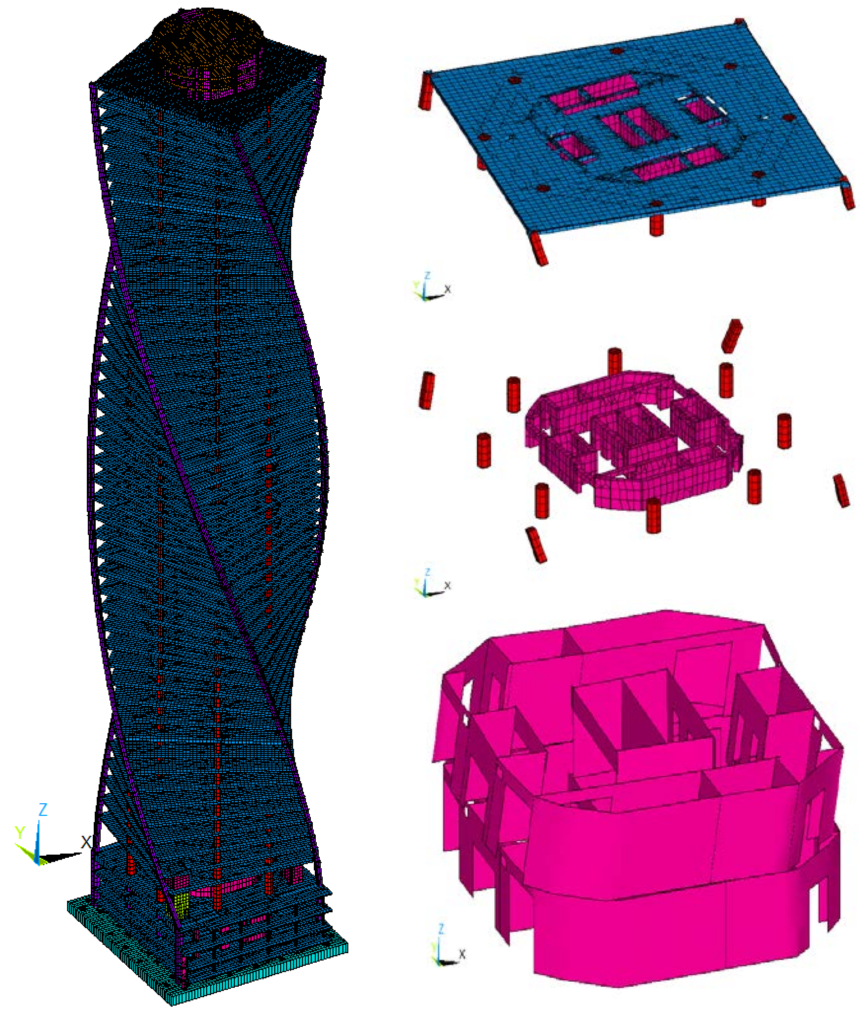
Structural damage after maximum design earthquake within physically nonlinear model, cased by to tension (at the top) and compression (at the bottom)

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Evolution tower of Moscow International Business Center "Moscow-City" with allowance for actual positions of reinforced concrete structures (ANSYS)



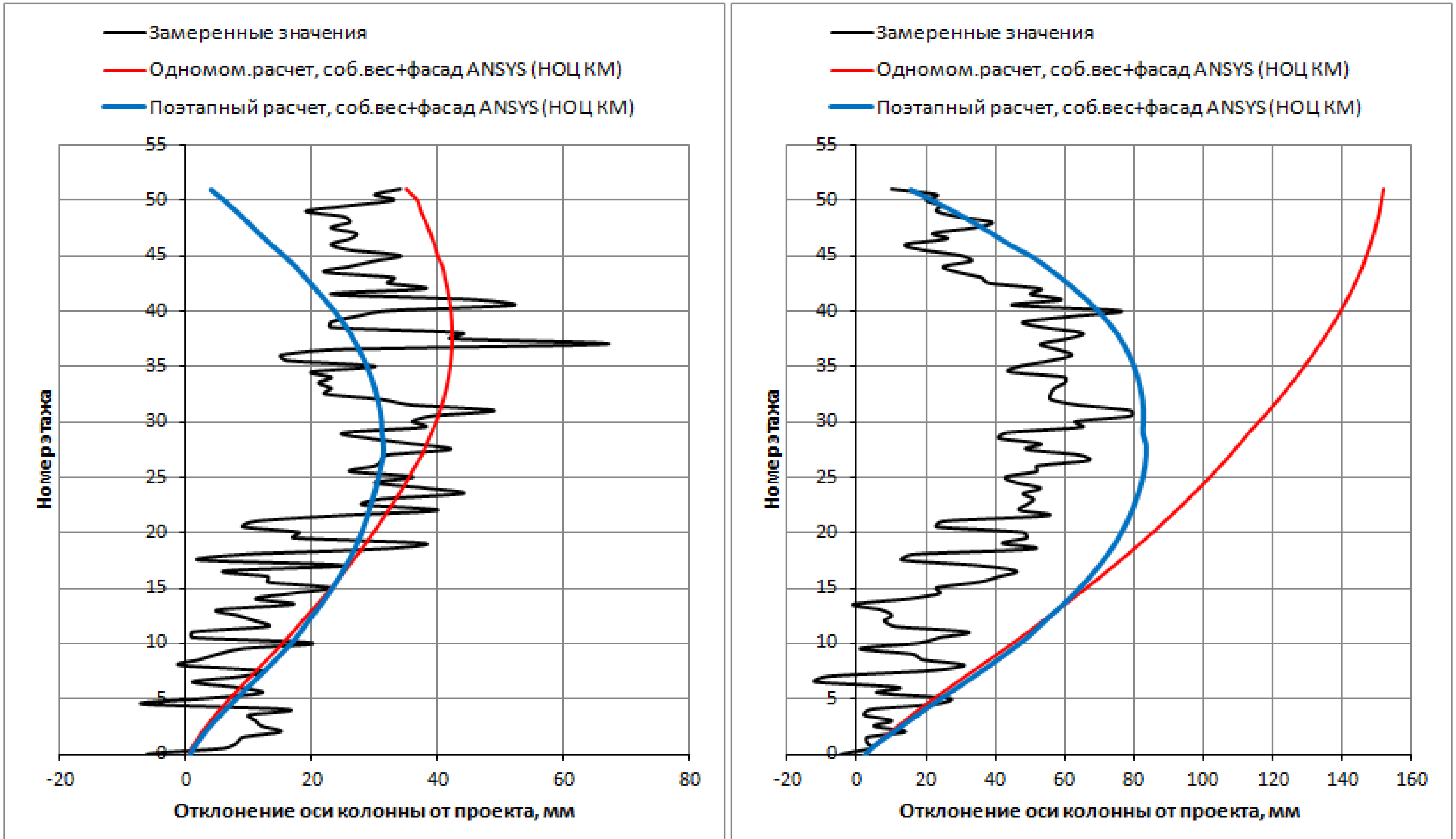
Evolution tower, construction phases
(Right image – state for July 2014



Finite element models, construction phases.
Allowance for actual geometric parameters of columns and walls

SAMPLES OF NUMERICAL MODELING

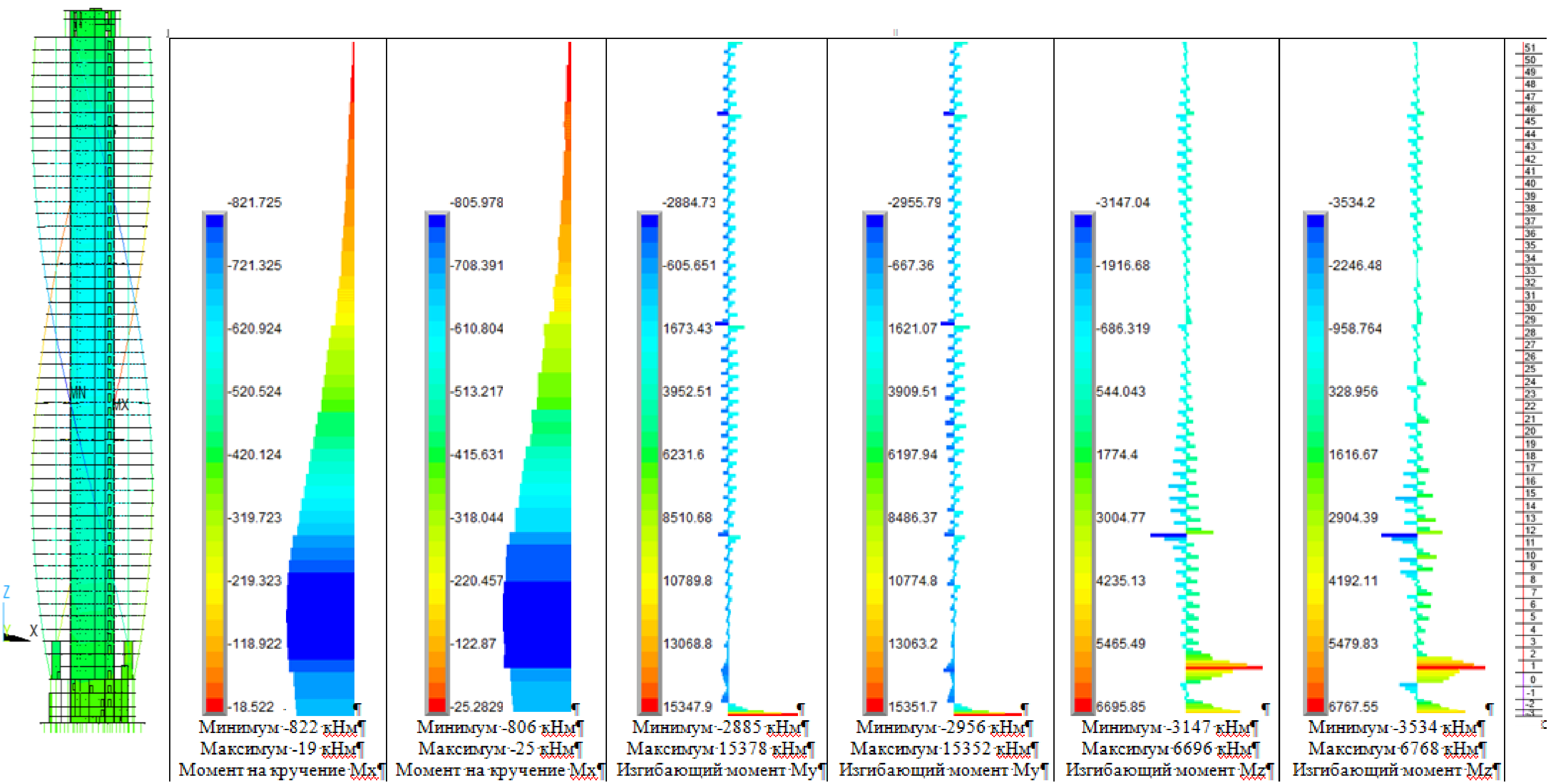
Analysis of stress-strain state, strength and stability of load-bearing structures of Evolution tower of Moscow International Business Center “Moscow-City” with allowance for actual positions of reinforced concrete structures (ANSYS)



The deviation of the column axis from the design position along the OX axis (left) and OY with allowance for deformation of the model. Loads: standard dead load from load-bearing structures, loads from facade structures (at the time of inspection).

SAMPLES OF NUMERICAL MODELING

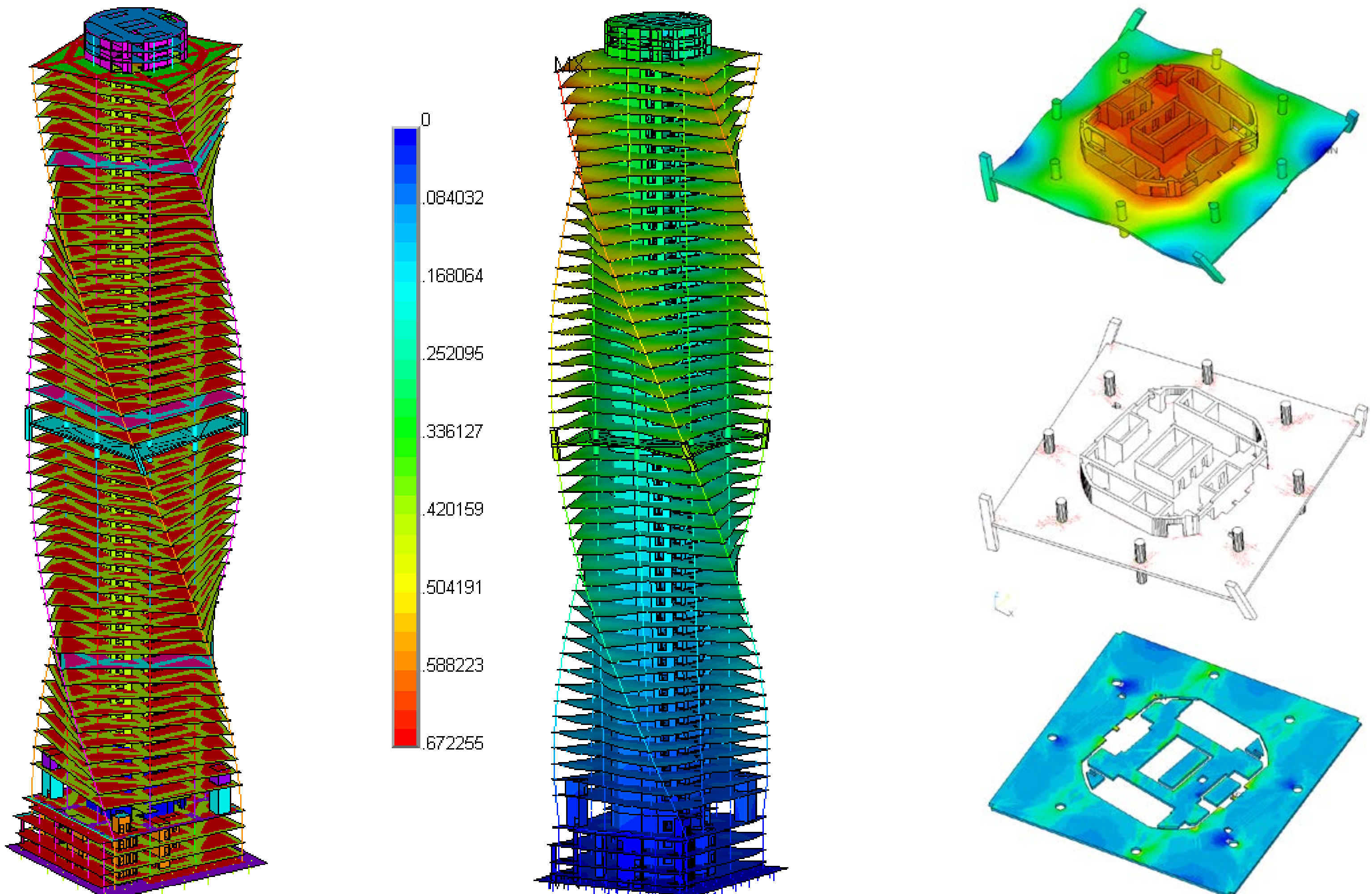
Analysis of stress-strain state, strength and stability of load-bearing structures of Evolution tower of Moscow International Business Center “Moscow-City” with allowance for actual positions of reinforced concrete structures (ANSYS)



Moments in column T1TC, “*design*” (*ideal*) and “*actual 1*” models, load combination 1.32SW+1.44Fac+1.56PN+0.504VN+Crown).

SAMPLES OF NUMERICAL MODELING

Analysis of stress-strain state, strength and stability of load-bearing structures of Evolution tower of Moscow International Business Center “Moscow-City” with allowance for actual positions of reinforced concrete structures (ANSYS)



Integrated finite element model Full CE model with built-in volumetric physically nonlinear model of a typical floor. Distribution of vertical displacements, cracks and stresses in longitudinal reinforcement.

THANK YOU FOR YOUR ATTENTION!

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