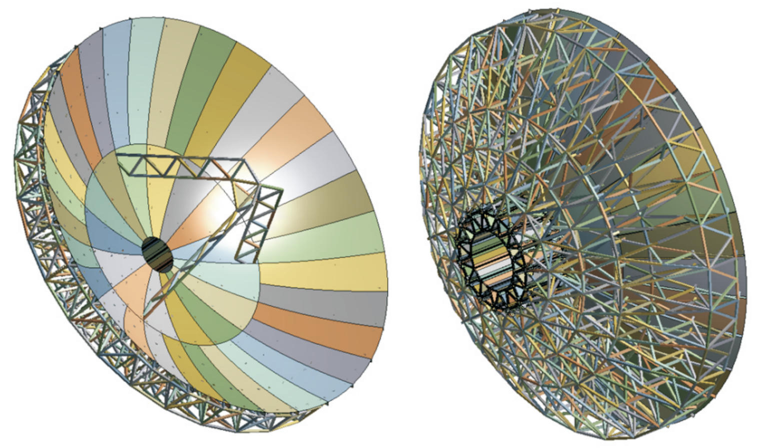

INFORMATION MODEL OF DAMAGE ACCUMULATION AND SURVIVABILITY FOR JOINT ASSEMBLY OF BEAM SKELETON

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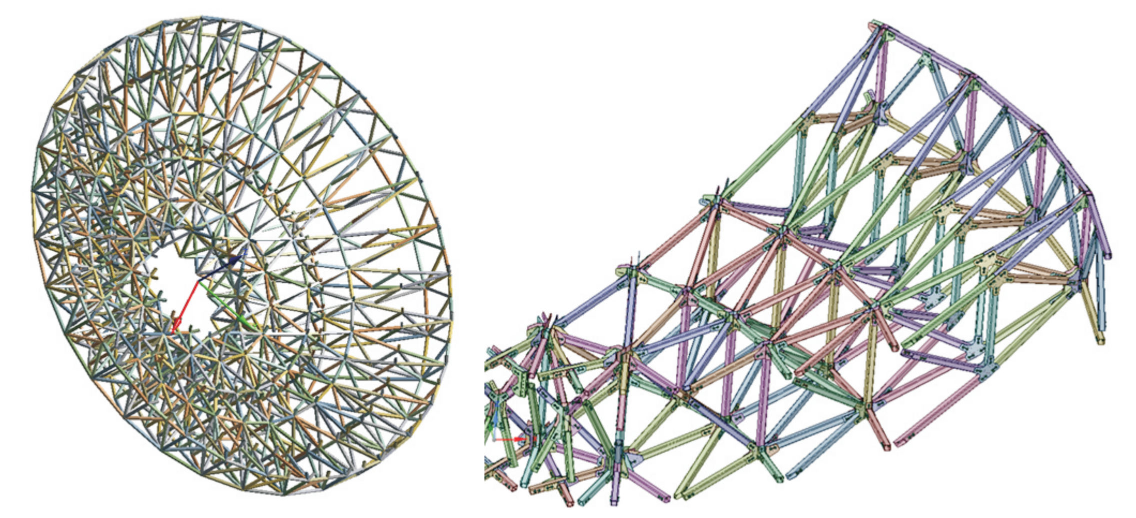

Joint assembly integrates composite pipes and fittings by means of bolting and glue joints. To elaborate information and computational model there are used frame library to determine parameters of system components and relations between them. The model involves numerical analysis of damaging and failure.

INFORMATION MODEL OF THE STRUCTURE AND STRUCTURAL STRENGTH

The elementary, multiple fragment of joint assembly contains the pipe and the fitting made of polymer composites of different structure, steel ring, bolts and nuts (*Fig. 1*). In spite of little number of structural components they are integrated into mechanical system by means of heterogeneous physical and technical connections: threaded connections, glue joints and frictional interactions. That is why the construction is characterized by high level of structural heterogeneity. Information model of structure and structural strength for the joint assembly contains two members: 1 – information models of structural components and connections between them; 2 – general formulation for all the strength conditions that specify structural integrity of the joint assembly.

Information models of structural components and connections between them are presented consist of frames that are data structures well defining the object. The aggregate of structural components, connections between them, and frames defining their properties composes information model of the construction (*Fig. 2*).

Formulations of strength conditions that specify structural integrity of the joint assembly are collected in the *Table 1*.

Violations of above-mentioned strength conditions occur at different times during life cycle. It is fundamentally important to consider these violations to be interrelated events and processes.

TABLE 1. Strength conditions

Limiting state	Strength conditions formulations
Components crushing by preloaded bolts	$\frac{F_0}{A^{bf}} < \sigma^f$, $\frac{F_0}{A^{sn}} < \sigma^s$, $\frac{F_0}{A^{sp}} < \sigma^p$, where F_0 – bolt tightening force; A^{bf}, A^{sn}, A^{sp} – accordingly surface contact area between bolt head and fitting, ring and nut, ring and pipe; σ^f, σ^s, σ^p – accordingly bearing strength for fitting, ring and pipe.
Bolts gripping relaxation	$F_0^{real} = F_0^{calc}$, where F_0^{real}, F_0^{calc} – accordingly actual and design bolt tightening force.
Adhesive layer destruction	$\sigma_{glue} < \sigma_{glue_{cr}}$, where σ_{glue} – maximum reduced stress in the adhesive layer; $\sigma_{glue_{cr}}$ – adhesive layer strength.
Joint closeness loss	$F_{st} < F_{fr}^{fp}$, where F_{st} – tensile force in skeleton beam; F_{fr}^{fp} – friction force between the bolted fitting and the pipe.
Ring destruction	$\sigma^s < \sigma_b^s$, where σ^s – maximum reduced stress in the ring; σ_b^s – ultimate strength of ring material.
Fitting destruction	$\sigma^f < \sigma_b^f$, where σ^f – maximum reduced stress in the fitting; σ_b^f – ultimate strength of fitting material.
Pipe destruction	$\sigma^p < \sigma_b^p$, where σ^p – maximum reduced stress in the pipe; σ_b^p – ultimate strength of pipe material.
Bolts shear	$\tau^b < \tau_{cut}^b$, where τ^b – maximum shearing stress in the bolt cross-section; τ_{cut}^b – bolt shear strength.

INFORMATION MODEL OF DAMAGE ACCUMULATION AT THE SURVIVABILITY STAGE

Multilevel process of damage accumulation is considered to be an information process and is studied as causal semantic net. It is an oriented graph which nodes describe the notions of the object domain, but arcs show relations between nodes. In this case the notions describe the damages that are related to any one heterogeneity. The arcs show causal relations. The semantic net developed in this way can be analyzed as a scenario of damage accumulation related to any one heterogeneity right until structural integrity loss. Multilevel damage process is characterized by a number of arcs that connect simultaneously progressing damages. Casual relations themselves are not obliged to be deterministically conditioned. They can represent various rate of causal conditionality. The information model corresponds to point of view that multilevel process of damage accumulation is a system with mutual influence and interdependence of individual damages progressing.

The worked out scenario model of multilevel process of damage accumulation can be interpreted as an information model of object survivability (*Fig. 3*). Structural components with localized damaging are associated with graph nodes related to these damages.

COMPUTATIONAL MODEL AND NUMERICAL RESULTS

Computational model of undamaged construction involves the basic resolving equations and algorithm for finite-element displacement method [7], as well as nonlinear procedures for solving three dimensional elastic contact problem with variable contact area and friction [8].

Formulation of numerical (finite-element) model of joint assembly suggests two load steps. Bolts preloading and identification of initial (inherent) stress state of mechanical system are realized at the first step. The aim of the second one is to carry out iterative algorithm for solving nonlinear contact problem.

The numerical model of joint assembly (*Fig. 4*) is developed with following physical and technical parameters. Material properties are: nut, bolt, ring – carbon steel with Young modulus E=210000 MPa, Poisson ratio v=0,3; fitting – woven polymer composite with E_x=E_y=60500 MPa, E_z=6900 MPa, v_{xy}=0,03, v_{yz}= v_{xz}=0,3, G_{xy}=19500 MPa, G_{yz}=G_{xz}=2700 MPa; pipe – unidirectional polymer composite with E_x=60900 MPa, E_y=27000 MPa, E_z=15000 MPa, v_{xy}=0,07, v_{yz}=0,4, v_{xz}=0,27, G_{xy}=G_{xz}=4700 MPa, G_{yz}=3100 MPa; friction factor is 0,15.

Survivability investigation is fulfilled with using numerical model (*Fig. 4*) and information model of joint assembly survivability (*Fig. 3*). The research procedure involved traversing semantic net branches (*Fig. 3*) with analysis intermediate stress-strain states of the system to determine the most possible trajectories of further scenario elaboration.

CONCLUSIONENSURE

The worked out information and computational models of damage accumulation and survivability ensure quantitative assessment of damaging processes in connection with any structural heterogeneity. These models are to be used for risk analysis of damages and decision making during life cycle.

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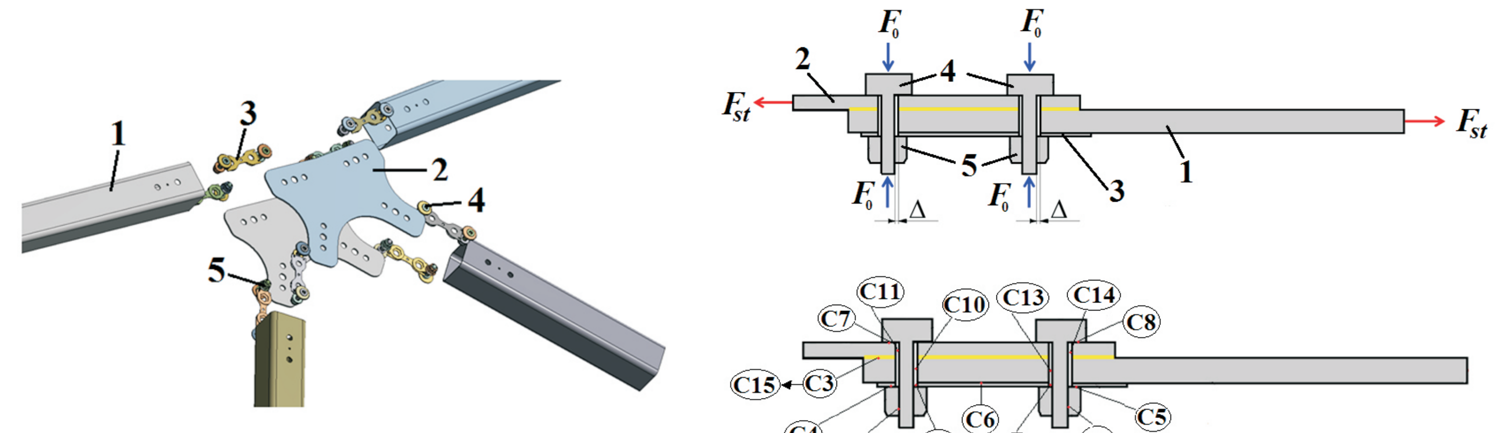

FIGURE 1. Scheme of joint assembly for pipe and fitting: 1 – pipe; 2 – fitting; 3 – ring; 4 – bolt; 5 – nut; C1, C2 – threaded connections; C3 – glue joint; C4-C15 – frictional interactions; Δ – clearance

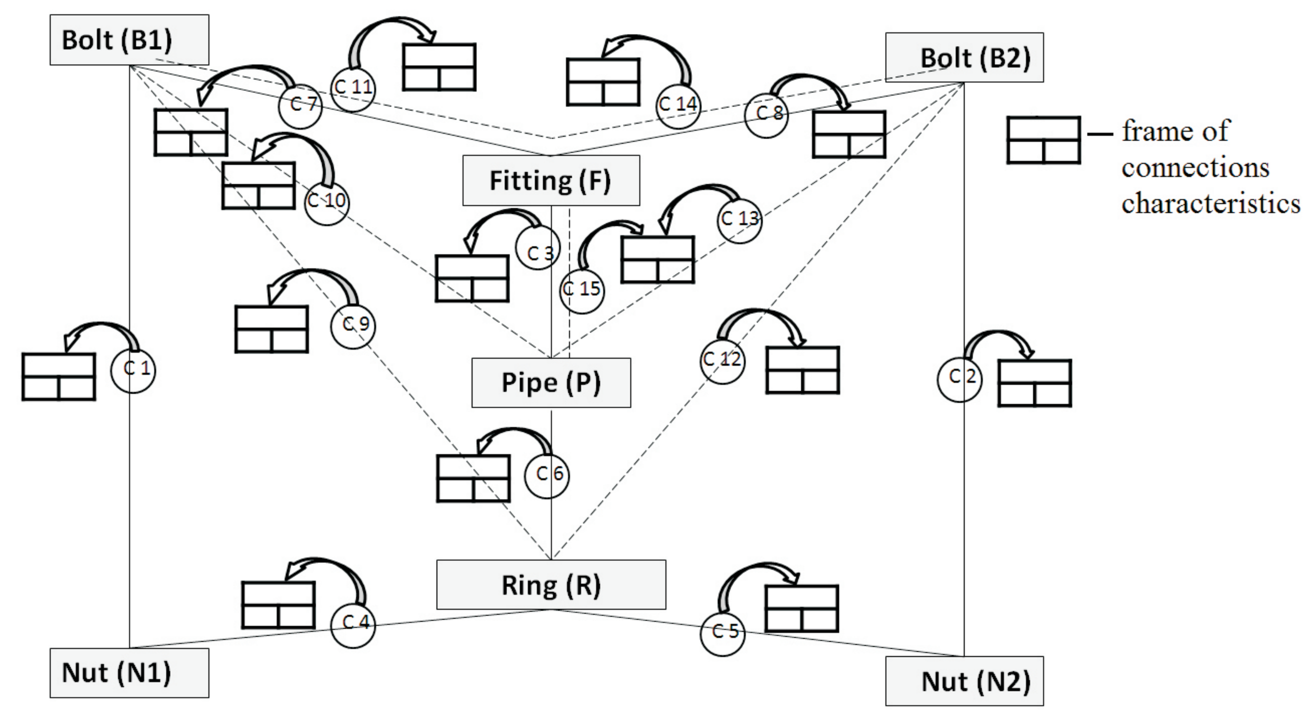

FIGURE 2. Information model of joint assembly for pipe and fitting

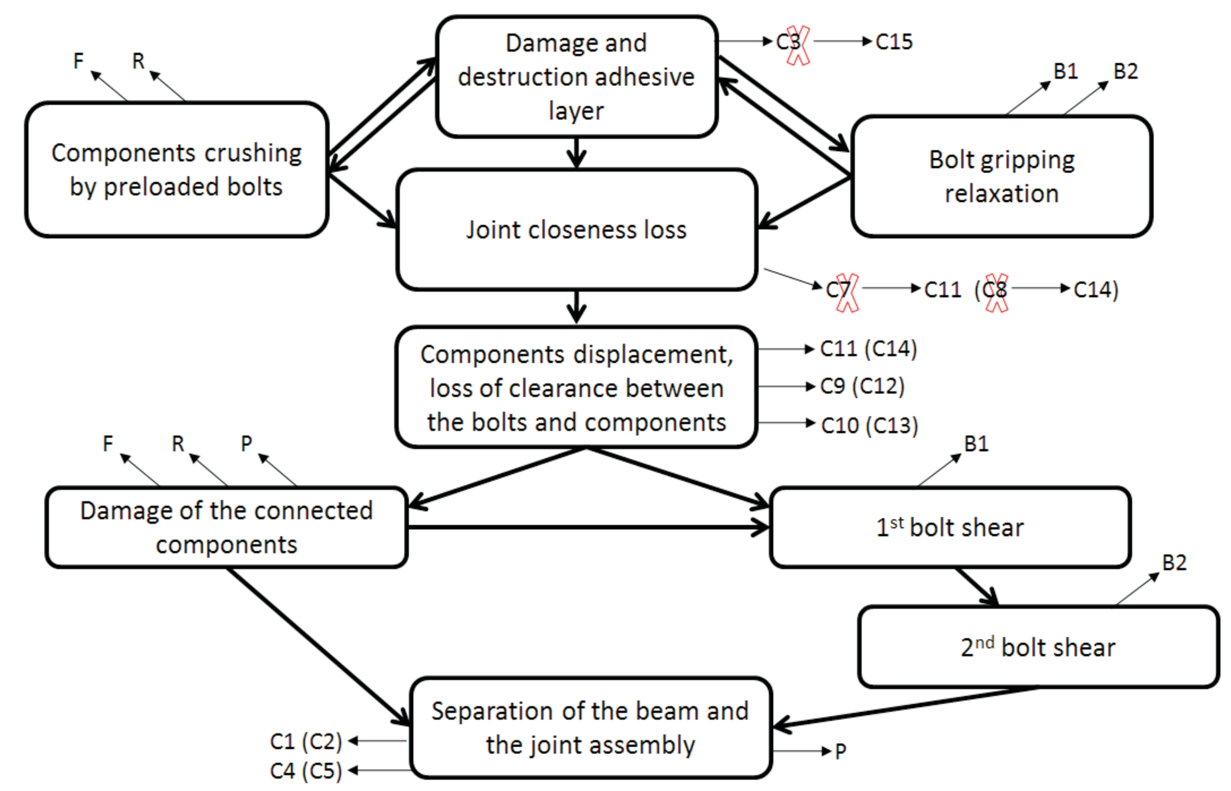

FIGURE 3. Information model of survivability of joint assembly

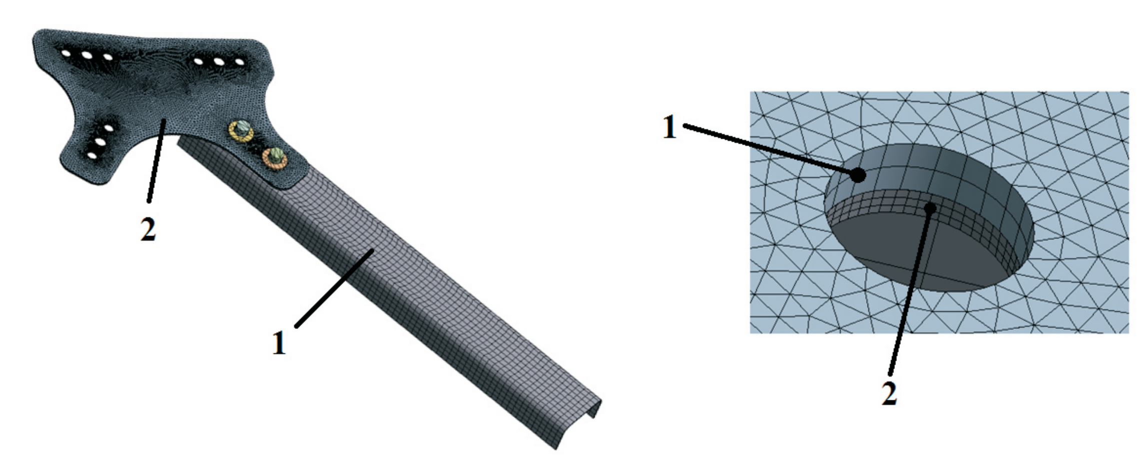

FIGURE 4. Finite-element model: approximately 71 thousand three-dimensional elements and 209 thousand nodes: 1 – pipe; 2 – fitting