УДК 621.01

Yerbol S. TEMIRBEKOV

(Almaty Technological University, Almaty)

ELASTOPLASTIC ANALYSIS
OF CONSTRUCTIONS LINK MECHANISM

Summary

This article describes finite element model fracture analysis for lever mechanism structures. In indeterminate structures exhaust of bearing capacity of one of its elements does not lead to its destruction, since the rest elements form an invariable system. The structure will reach its limit state only in case of bearing capacity is exhausted in as many elements as it is required for provision of its geometrical shape stability. This idea is taken as a basis for the below analysis and is explained with an example of excavator bucket calculation. Consideration of elastic-plastic strains provides more efficient use of structure integrity resources and material saving.

Fracture analysis is performed by means of steady external load increase from zero and until the structure released from a number of links due to formation of plastic hinges becomes a geometric one and this corresponds to bearing capacity exhaust. The structure kinematics should be considered in release from links. Geometrical stability does not result from static indeterminacy. A system with zero or negative mobility may appear to be a stable one. Therefore, in model preparing and further calculations it should be taken into account that:

1. Although in general lever mechanism design may be characterized by multiple statistical indeterminabilities, their geometric stability is not always obvious. Although construction linkage may be, in general, many times of redundancy their geometric invariability not always obvious. According to their purpose these structures are mechanisms, that is they are geometrically unstable systems and their immobility in the calculation via finite element method is provided only by the availability of a driving link fixed in any calculated position.

2. In elastic-plastic analysis of lever mechanism design via finite element method only nonlinear behavior of the subsidiary elements dependent on the main rods movement transmitting the motion of the structure in general should be considered.

Keywords: mechanism, structure, elastic-plastic strain.
Түйінді сөздер: тетік, құрылым, серпімдіпластикалық деформация.

Ключевые слова: механизм, конструкция, упругопластическая деформация.

1. Introduction. This idea is behind the Gvozdev's theory taken as a basis for calculation Ref. [1]. Elastic-plastic strain theory offers the challenge for more efficient use of structure integrity resources and material saving. The figure below illustrates that lever mechanisms have multiple uncertainty (Figure 1, 2).

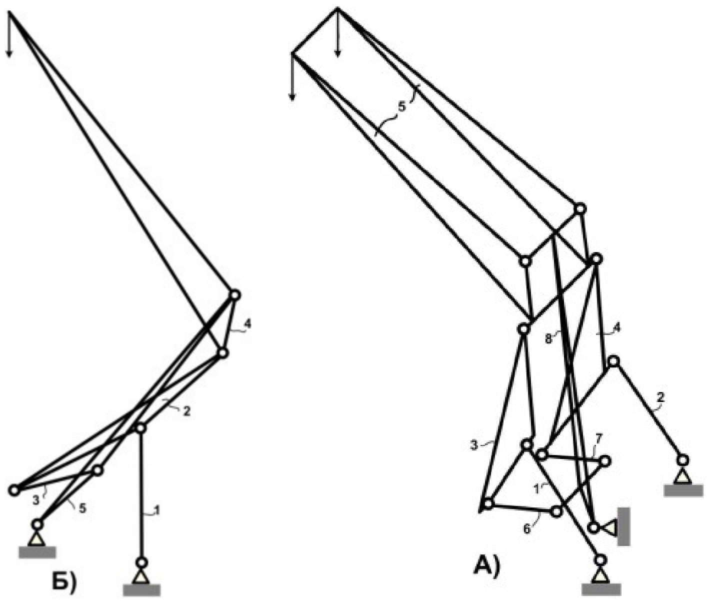


Figure 1 – Lifting mechanism VSHD-6:

a) W = 6*8-5*13 = -17, b) W = 3*5-2*7 = 1

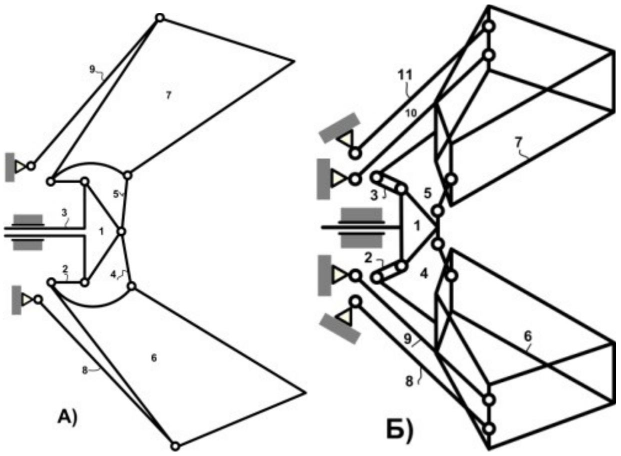
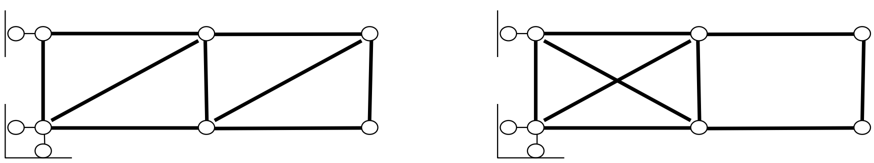


Figure 2 – Class III Bucket Grab: a) W = 3*9-2*13 = 1, b) W = 6*11-5*17 = -19

Fracture analysis is performed by means of steady external load increase from zero and until the structure released from a number of links due to formation of plastic hinges becomes a geometric one and this corresponds to bearing capacity exhaust. THE STRUCTURE KINEMATICS SHOULD BE CONSIDERED IN RELEASE FROM LINKS.



a) b)

Figure 3 – a) statically determinate and geometrically stable girder,

b) statically indeterminate and geometrically unstable girder

Geometrical stability does not result from static indeterminacy. A system with zero or negative mobility may appear to be a stable one. An example is shown in Figure 3. Therefore, in model preparing and further calculations it should be taken into account that:

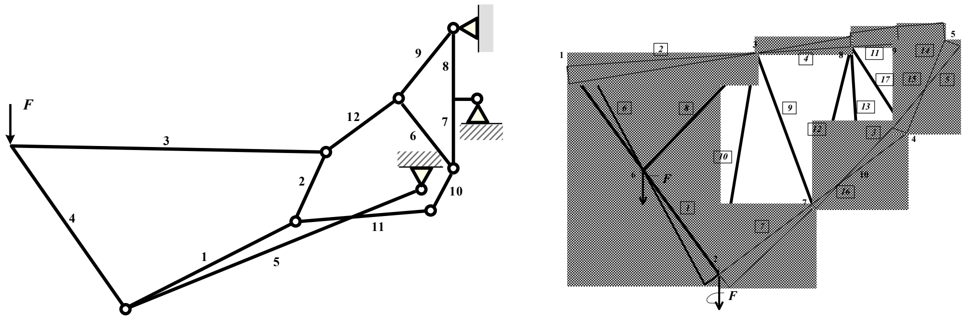
1. Although in general lever mechanism design may be characterized by multiple statistical indeterminabilities, their geometric stability is not always obvious. According to their purpose these structures are mechanisms, that is they are geometrically unstable systems and their immobility in the calculation via finite element method (FEM) is provided only by the availability of a driving link fixed in any calculated position.

2. In elastic-plastic analysis of lever mechanism design via finite element method only nonlinear beha-vior of the subsidiary elements dependent on the main rods movement transmitting the motion of the structure in general should be considered.

2. Model mechanisms. Calculations are made with the computer-aided design system “Lira” Ref. [2]. Simulation of the structure materials physical nonlinearity is made with physically nonlinear finite elements receiving information from the developed Library of Material Strain Laws. The Library of Material Strain Laws allows considering almost any physically nonlinear material properties. In the example under consideration a piecewise linear dependence between stress and deformation is analyzed. Stiffness matrix of the linearized physically nonlinear system is formed on the basis of the variable integral stiffness, calculated at the points of the finite element integration in solving of the elastic problem for the particular step. The finite element numerical integration scheme and a set of the rigidities used are determined by the type of the finite element. In order to obtain a corresponding set of integral rigidities the cross section of the finite element at the points of integration is divided into a number of the elementary sub-regions. New values of the physical and mechanical characteristics of the material are determined in the centers of these sub-areas in accordance with the prescribed strain pattern. At each step the linearized problem with formation of a tangent modulus displacement vectors, loads, and new integral rigidities for the next step is solved.

3. Example. Let us take the calculations for a single-bucket hydraulic excavator as an example. Let’s assume that the structural elements of the bucket are made of steel St3. The elastic limit is 220 MPa. The yield strength is 223 MPa. The yield line voltage is 223.2 MPa. The tensile strength is 400 MPa. Thus, the strain law will consist of four sites, two per the stretched and compressed zones, since different signs voltages occur in the elements of the mechanisms and this should be considered in non-linear calculations. The stress-strain of state of each non-linear finite element is evaluated at each step of the iterative process. It is analyzed for the rod finite elements on the basis of the rod cross-sections at the points of division. In the present case five elementary rings and 16 elementary sectors are considered. It is assumed that the elements of the mechanism are made of tubes with an outer diameter of 4 cm and an inner diameter - 3.6 cm.

Let’s consider the nonlinear behavior of the excavator bucket, excluding the remaining elements bringing the bucket into a predetermined position (Figure 4a shows the bucket as the chain – 1-2-3-4). The bucket is modeled by the system of rod elements fitting the bucket stiffener, since these elements bear main workload. The scheme of the drive with bucket for the lowest position is shown in Figure 4a.

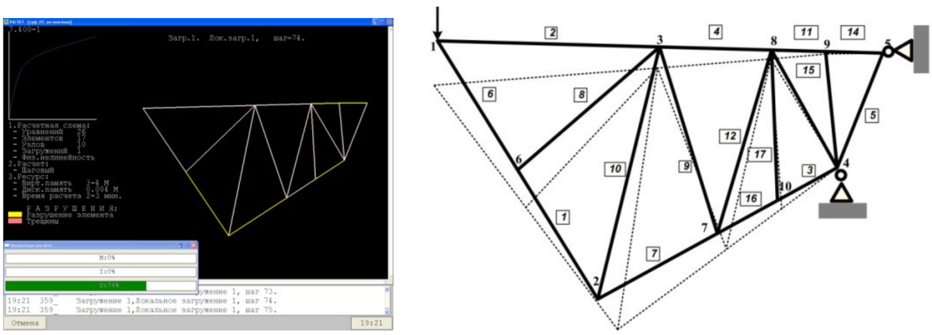


a) b)

Figure 4 – a) Kinematic scheme of the bucket with the drive;

b) Diagrams of bending moments in the elements of the bucket model

Two options of bucket loading are considered in calculations first - at the time of load lifting (the load is at the bottom of the bucket, and this corresponds to loading of the units 2, 6, 7) and at the time of the capture of the load (concentrated forces are applied in the upper left unit of the bucket - unit 1). Only option 1 is desxcribed in this paper. Option 1 (load lifting). Linear calculation of the bucket shows that it works similar to the frames. Longitudinal forces, shear forces and bending moments (Figure 4b) occur in the bucket elements. The greatest bending moments occur in elements 3 and 14, i.e. these elements determine the carrying capacity of the bucket as a whole in elastic finite element calculations. Nonlinear calculation of the bucket (Figure 5) shows that the initial plastic hinge develops in the element 3, when total load reaches 3.86 tons Then the plastic hinge develops in element 14 at total load of 4.56 tons, in element 7 - at total load of 4.5 tons, in the element 11 - at a load of 5.84 tons and at the load of 6.16 tons the structure fails. Thus, from the time of formation of the first plastic hinge to the complete destruction of the structure the external load increases 4.56 tons to 6.16 tons, i.e. by 35%. The form of the bucket at the moment of fracture is shown in Figure 5.



a) b)

Figure 5. a) A non-linear calculation of the bucket, b) Deformed bucket scheme at the time of destruction

4. Conclusion. The above calculations of the lever mechanism structures finite-element models destruction show that consideration of elastic-plastic strains provides better use the structure integrity resources and material saving.

REFERENCES

1 Rzhanitsyn A.R. Calculation of structures taking into account the plastic properties of the material. – Moscow: Higher School, 1984. – P. 327.

2 Software package “Lira” for structural analysis and design. Version 9.0. User's Guide. – Volume 1. Theoretical and computational basics. Recommendations. – Kiev, NIIASS, 2002. – P. 147.

Резюме

Ербол Садуақасұлы Темірбеков

(Алматы технологиялық университеті, Алматы қ.)

ШЫНЖЫРЛЫ ТЕТІК ҚҰРЫЛЫМЫНЫҢ

СЕРПІМДІ ПЛАСТИКАЛЫҚ ТАЛДАУЫ

Шынжырлы тетік құрылымының соңғы элементтік үлгісінің қирау есебі баяндалған. Анықталмаған құрылымның бір элементінің тасымалдаушы қабілетінің жойылуы, өзгермейтін жүйенің қирауына әсер етпейді. Құрылымды межелі жағдайға немесе күйге жеткізу үшін қажетті элементтердің тасымалдаушы қабілеттері құрылымның геометриялық тұрақтылығын қамтамасыз етуі тиіс. Бұл идея есептеудің негізі ретінде алынған және эксковатор шөмішінің есебінде көрсетілген. Серпімді пластикалық деформация есебінде құрылымның беріктілік мүмкіншілігін толығымен пайдалану материалдың үнемділігін арттырады. Итерациялық әдіспен есептеу арқылы сыртқы жүктемені нөлден қажетті жағдайға жеткізу, құрылымның бірнеше байланыстары босатылуының арқасында пластикалық топсаға айналуы, геометриялық еместігі тасымалдаушы қабілетінің жойылуына әкеліп соқтырады. Байланыстарды босату кезінде құрылымның кинематикасын ескеру қажет. Геометриялық өзгермеушілік статикалық анықталмаушылыққа тікелей бағынбайды. Жүйенің нөлдік немесе теріс қозғалысы геометриялық өзгермелі болуы мүмкін. Сондықтан үлгі дайындауда және оны есептеуде төмендегі жағдайларды ескеру қажет:

1. Жалпы жағдайда шынжырлы тетік құрылымы статикалық анықталмаған болғанмен, оның геометрия-лық өзгерімділігі тұрақты емес. Бұл тетіктер – өздерінің мақсаттары бойынша геометриялық өзгермелі жүйе және олардың қозғалыссыздығы соңғы элементтердің әдістерін есептеуде белгіленген жетекші буынның жағдайы ескеріледі.

2. Шынжырлы тетіктер құрылымында соңғы элементтер әдісімен серпімді пластикалық есептеуде көмек-ші элементтердің сызықты емес бағытын ескеру керек, қозғалыс негізгі өстер қозғалысы арқылы құрылымға берілетін қозғалысқа байланысты.

Түйінді сөздер: тетік, құрылым, серпімді пластикалық деформация.

Резюме

Темирбеков Ербол Садуахасович

(Алматинский технологический университет, г. Алматы)

УПРУГОПЛАСТИЧЕСКИЙ АНАЛИЗ

КОНСТРУКЦИЙ РЫЧАЖНЫХ МЕХАНИЗМОВ

Изложен расчет разрушения конечно-элементных моделей конструкций рычажных механизмов. В статически неопределимых конструкциях исчерпание несущей способности одного из элементов не вызывает ее разрушения, так как остальные элементы образуют неизменяемую систему. Предельное состояние всей конструкции будет достигнуто только тогда, когда исчерпается несущая способность стольких элементов, сколько требуется для обеспечения ее геометрической неизменяемости. Эта идея взята за основу расчета и показана на примере расчета ковша экскаватора. Учет упругопластических деформаций более полно использует ресурсы прочности конструкции и приводит к экономии материала. Расчет ведется итерационным методом путем увеличения внешней нагрузки от нуля до тех пор, пока конструкция, освобожденная от ряда связей из-за образования пластических шарниров, не окажется геометрически, что соответствует исчерпанию несущей способности. Необходимо при освобождении от связей учитывать кинематику конструкций. Геометрическая неизменяемость непосредственно не следует из статической неопределимости. Система, имеющая нулевую или отрицательную подвижность, может оказаться геометри-чески изменяемой. Поэтому при подготовке модели и при расчете необходимо учитывать, что:

1. Хотя конструкции рычажных механизмов могут быть, в общем случае, много раз статически неоп-ределимыми, их геометрическая неизменяемость не всегда очевидна. По своему назначению – это механиз-мы, т.е. геометрически изменяемые системы и их неподвижность при расчете методом конечных элементов обеспечивается только наличием фиксированного в каждом расчетном положении ведущего звена.

2. При упругопластическом расчете конструкций рычажных механизмов методом конечных элементов учитывают нелинейное поведение лишь вспомогательных элементов, движение которых зависит от движения основных стержней, передающих движение конструкции в целом.

Ключевые слова: механизм, конструкция, упругопластическая деформация.

Поступила 14.03.2013г