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Satbayev University

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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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DETERMINING LIMIT DISPLACEMENTS IN SPACER PROPPING SINGLE BOLTING

Abstract. Using the existing engineering methodology of designing bolt joints taking up shear loads of dimension chains with gap elements according to N. N. Streletski and other authors' methodology give similar results, both for the analysis of single bolt joints accuracy and for that of multi-bolt joints. In this article there is considered the affect of gap elements number on the accuracy of multi-bolt joints. There is established the character of the intrinsic errors distribution functions interaction, particularly, limit displacements occurring when mounting single bolt joints, and errors distribution functions determining the accuracy of multi-bolt joints elements mutual orientation. There are considered theoretical schemes of forming setting errors for basic elements in the plane of formed joints for a more complicated case, when shearing forces cause element displacements not obligatory reaching limit values. An analysis of the revealed theoretical schemes for the formation of displacements of the installed elements in the plane of the formed bolted joints shows that the parameters of the displacement distribution are significantly different from the same parameters obtained when calculating dimensional chains with gap units.

Key words: dowel, self-anchoring bolt, spacer propping, "bolt-hole" coupling, linear and angular displacement, multi-bolt joint, setting error.

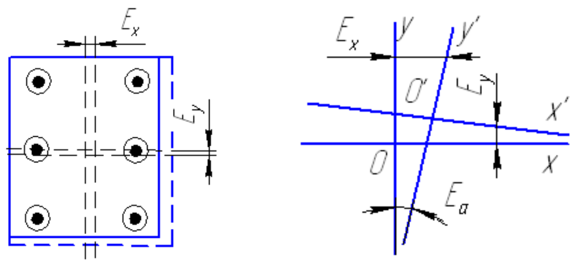
Introduction. In the conditions of permanently increasing level of building technology industrialization, when manufacturing buildings and structures parts is in the increasing degree transferred to plant conditions, there changes the structure of working on the site. Operations on assembly acquire the growing significance, the main of them being quality coupling and bolting. Lately among the main requirements there are setting fastening elements with the least labor content, reducing the work executing and achieving high bearing capacity of the joint on the whole. Besides, setting simplicity and aesthetics of the joint structures themselves are an integral requirement. Studying the now used traditional methods of the equipment fastening to the buildings bearing structures (embedded parts, special consoles, metal buckles, coupling rods, bolts and pins) showed that they do not satisfy the present day requirements to them. High labor intensity of the work executing is combined with significant metal consumption for making coupling strcxutures. Studying bolt joints taking up shear loads is dealt with in the works by N.S. Streletski [1], G.A. Shapiro [2], N.N. Streletski [3], A.F. Knyazhev [4] and other authors [5,6,7,8]. In these works it is shown that the bolt joints bearing capacity and deformability (including the ones taking up vibration loads) are affected by the whole number of factors, the main of which can be divided into four groups: C_1 – a group of parameters including technological factors of bolt joints manufacturing; C_2 – a group of parameters defining the joint friction effect characteristics; C_3 – a group of parameters including geometrical characteristics and mechanical properties of couples elements and bolts materials; C_4 – a group of parameters affecting the irregularity of force distribution between multi-bolt joint bolts. There was noted that deformability was the main criterion of rational selecting a joint type and defining breaking stress that can be taken up by the joint working on shear. However, the question was considered in a general conception, and there were not considered the main displacements and deformations of multi-bolt joints. The joint shear complete displacement S_{full} is the sum of displacements and deformations consisting of the following components:

$$S_{full} = S_{s.d} + S_s + S + S_{d.b} + S_y\ , \tag{1}$$

where S_c is the joint general shear displacement whose value depends on the accuracy of making holes and the difference between the hole diameter and the bolt body; S_s is shear and bending deformation of the bolt body; S is crushing deformation of the coupled elements; $S_{d.b}$ is crushing deformation of the bolt body; S_y is longitudinal elongation (shortening) deformation of the coupled elements sections between the bolts.

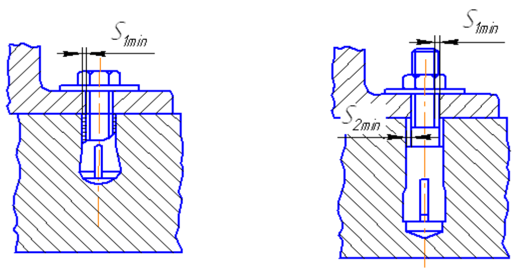
For bolt joint shear operation there is characteristic developing significant displacements – S_{full} (5-8 mm) opposite to which the sum of deformations $S_{d.b}$ and S_y (0,03-0,1 mm) is small and negligible.

The accuracy of setting basic elements in the plane of the formed couplings with the bearing structure surfaces is quantitatively characterized by the values of the set elements displacements from the nominal position. The setting processes performed by the way of aligning the holes in the basic elements with the set in the structure mass anchors (dowels) refer to partially regulated processes, for which error occurring is related to the presence of gaps in the “bolt-hole” couplings (figure 1a). Due to the mentioned gaps the set elements have three degrees of freedom in the plane of the formed couplings with the building bearing surfaces. In Figure 1b it is shown that occurring in setting basic elements deflections from the nominal position present linear displacements E_x and E_y of $0'X'$ and $0'У'$ axes, as well as their angular displacements E_α relative to the specified coordinate system X_{0Y}.



a) b)

Figure 1 – Presence of gaps in “bolt-hole” couplings:
a) set elements with gaps;
b) linear and angular displacements in couplings



a) b)

Figure 2 – Coupling with dowels: a) holes for passing bolts are designed only in the basic elements; b) gaps are both in the basic elements and in anchor unit elements

The analysis of coupling basic elements and buildings bearing structures with dowels permitted to separate two most characteristic types of bolt joints. In figure 2 there are presented variants of dowel joints.

Their constructional difference is defined by characteristic features of dowel coupling with basic element holes and anchor unit elements. In the joints in figure 2a (A-type) holes for bolt passing are designed only in the basic element, and dowel-bushes themselves are placed in the concrete body without gaps. In the joints in figure 2b (B-type) the holes for bolt passing and gaps, respectively, are both in the basic elements and in anchor unit elements. It is obvious that in case of forming the second type joints orientation of the elements placed in the bearing structure planes, will be performed within the limits of the total gap. Taking into account constructional characteristic features of anchor bolts coupling, the formulae to determine minimal guaranteed gap and designing limit linear displacements of the set elements have the following form:

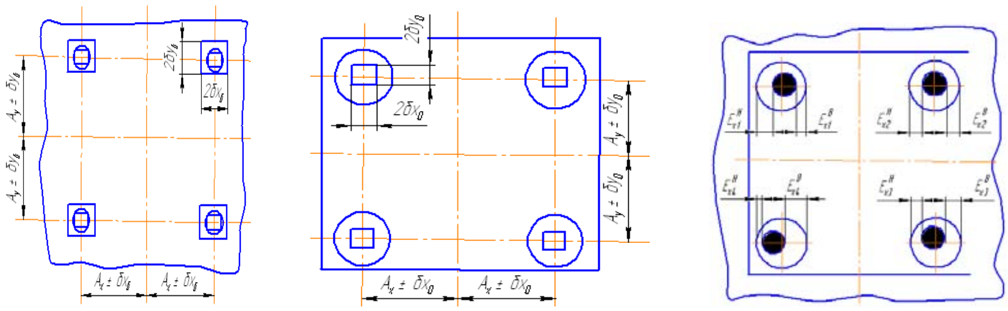
$$S_{min} = \frac{2\sqrt{(\delta_{X0} + \delta_{X\delta})^2 + (\delta_{Y0} + \delta_{Y\delta})^2}}{K}, \tag{2}$$

$$E_{X(Y)} = \pm(0{,}5 \times S + \sqrt{\delta_{X(Y)_0}{}^2 + \delta_{X(Y)_\delta}{}^2 + \delta_S{}^2}), \tag{3}$$

where $\delta_{X(Y)_0}$ is an admissible deflection of the hole axes in the basic element from the nominal position; $\delta_{X(Y)_\delta}$ is an admissible deflection of anchor dowels axes from the nominal position; δ_{x0}, δ_{y0}, $\delta_{x\delta}$, $\delta_{y\delta}$ are admissible deflections; $S_{min}= S_{min1}$, $\delta_S = \delta_{S1}$ for A-type couplings; $S_{min}= S_{min1}+S_{min2}$, $\delta_S = \sqrt{\delta_{S1}{}^2 + \delta_{S2}{}^2}$ for B-type couplings.

When analyzing present day methods of ensuring the accuracy of assembling bolt joints, it was established that the designing relations in N.S. Streletski's work do not take into account the affect of the "bolt-hole" couplings number on the value of limit displacements. That is using the existing engineering methodology of designing dimension chains with gap elements gives the same results both for the analysis of single bolt assembling accuracy and for multi-bolt couplings [9,10,11,12,13].

Research part. Let's consider in general the affect of the couplings number with gaps on the accuracy of multi-bolt joints assembling. Here we'll try to establish the character of interaction of intrinsic errors distribution functions, particularly, limit displacements occurring when assembling single bolt joints, and errors distribution functions defining the accuracy of the coupled elements mutual orientation in multi-bolt joints [14,15,16,17]. To solve the problem posed let's consider the schemes shown in figure 3. The first one shows clearly the location of the set dowels deflection axes from the nominal position specified by the coordinating dimensions A_x and A_y. Deflection fields are shown in figure 3a as shaded squares. Similarly there are shown the holes deflection fields in the basic elements (figure 3b).



a) b) c)

Figure 3 – Layout chart: a) admissible deflection fields of anchor bolts;
b) admissible deflection fields of hole in the support; c) bolts and holes when setting a basic element

In the neat scheme there is presented a set basic element with the complete alignment of its axes with the specified axes, i.e. the element setting errors in the joint plane are equal to zero. Besides, the holes in the element have random deflections within the admissible allowances, and anchor units axes are randomly oriented within the limits of allowances for setting anchor units. That's why in the scheme (figure 3c) the side gaps between the hole walls and dowel bodies have different values presenting a part of the diametrical gap S complete value. It is obvious that with the basic element displacement from the nominal position the value of the limit displacement will be restricted in the considered direction by the minimal of all the side gaps. As for the case shown in Figure 3c, the limit displacements in the positive $E_{xв}$ and negative $E_{xн}$ directions of X-axis will be equal respectively to the side gaps in the first and the fourth "bolt-hole" couplings. Let's note that for real assembly processes occurring the set element displacements described by relations (2) and (3), is connected with the conditions of the basic element aiming to the anchor bolts. It is clear that in the considered case the aiming error is no less than the value of "bolt-hole" coupling gap.

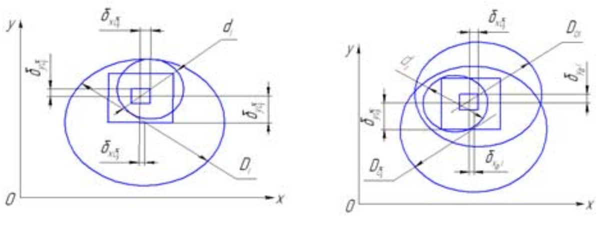
Let's consider theoretical layouts of forming basic elements setting errors in the plane of the formed joints for a more complicated case, when shearing forces cause displacing elements nor obligatory reaching the limit values. This case corresponds to real assembly processes with a more accurate that in the abovementioned example basic element aiming to the dowels. Besides, the set element is randomly oriented in the limit values range. Let's suppose that we know the law of limit values g(Ex) distribution and that there has been established the law of the set element distribution within the limits of gaps in the direction of X-axis. Then the theoretical law of displacements distribution accounting a random factor of limit values will correspond to the layout of unconditional and conditional distributions which can be presented in the general form as follows:

$$g(x) = \int_{\psi(E_X)}^{\infty} g(x) g_0(x) d(E_x), \qquad (4)$$

where $\psi(E_x)$ is the function describing the dependence of integration limit value on E_x changes.

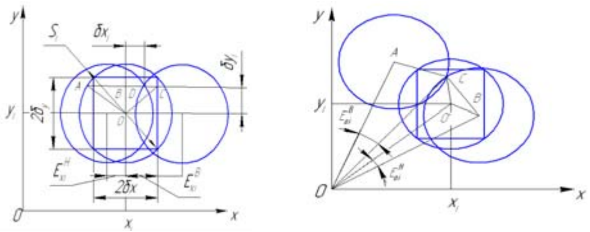
The character of E_x displacements distribution is true for displacements E_y, E_α.

The analysis of the revealed theoretical schemes of forming displacements of the set elements in the plane of the formed bolt joints shows that parameters of the displacements distribution differ significantly from the similar parameters obtained in designing dimensions chains with gap elements [18,19,20]. Besides, changing the parameters of element displacements distribution is oriented to the side of increasing the accuracy of these elements setting which proves the presence of accuracy reserves and reducing assembly processes labor intensity. To derive the relations permitting to define limit displacements of the set element in the plane of the formed bolt joint depending on the real values of geometrical characteristics of the i-th coupling with a gap, let's consider the schemes presented in Figure 4. In the schemes there is shown the mutual location of bolts and holes axes of the i-th coupling with a gap when aligning the axes of the set element with the specified axes and forming A-type couplings (figure 4a) and B-type (figure 4b). The holes and bolts are shown with deflections from the nominal position specified by X_i, Y_i dimensions within the limits of δ_{x0}, δ_{y0}, $\delta_{x\delta}$, $\delta_{y\delta}$ allowances. The holes and bolts are schematically shown by the circles whose diameters are designated D_{1i}, D_{2i}, d_i.



a) b)

Figure 4 – Mutual location of the bolts and holes of the i-th coupling with a gap: a) A-type coupling; b) B-type coupling



a) b)

Figure 5 – Layout for limit displacements designing: a) in the direction of X-axis; b) with the basic element turning

With the aim of simplifying the further computation, let's reduce the number of geometrical characteristics considered by means of introducing indicators in less detail. Starting from geometrical relations, we'll move from the holes and dowels diametrical dimensions to the gaps values and from the holes and dowels axes location deflections to their mutual location values: S_i is a diametrical gap (total); $S_i = D_{1i} - d_i$ for A-type joints; $S_i = D_{1i} + D_{2i} - 2_{di}$ for B-type joints; δ_{xi}; δ_{yi} are deflections of the holes and dowels axes mutual location ($\delta_{xi} = \delta_x\delta_i - \delta_{x0i}$; $\delta_{yi} = \delta_y\delta_i - \delta_{y0i}$). In Figure 5 using the designations there are presented the set element nominal and limit position with displacement in the direction of X-axis (figure 5a) and with the element turning (figure 5b). As shown in Figure 5a, limit displacement values E_{xi}^{B} и E_{xi}^{H} are defined by the lengths of AD and DC sections. It is easily seen that AD section is equal to the sum of AB and BD sections, and CД section is equal to the difference of BD and BC sections (AB).

Taking into account that ВД section is equal to δ_{xi} deflection, AB section is the leg of the right-angle triangle AOB, whose hypotenuse AO is equal to half-diameter gap AO = 0,5S_i, and leg OB is equal to δ_{yi} deflection, from geometrical relations we'll obtain:

$$E_{Xi}^{B(H)} = \delta x_i \pm \sqrt{0{,}25 S_i^2 - \delta_Y^2} \qquad (5)$$

When opening the introduced designations δ_{xi} and δ_{yi}, let's write down expression (5) in the form:

$$E_{Xi}^{B(H)} = (\delta x_{\delta i} - \delta x_{0i}) \pm \sqrt{0{,}25 S_i^2 - (\delta y_{\delta i} - \delta y_{0i})^2} \qquad (6)$$

In order to determine limit angular displacements $E_{\alpha i}^{B}$ and $E_{\alpha i}^{H}$, let's consider figure 5b.

Considering positive the basic element turn counterclockwise, let's designate angle $AOO^{/}$ as equal to angular displacement E_{α}, respectively, $O^{/}OB=E$. Taking into account that angles AOC and COB are equal, as AO = OB = x + y, and OC is the common side of triangles ACO and BCO, we'll obtain:

$$E^{B}_{\alpha i} = \angle O^{/}OC + \angle AOC, \qquad E^{H}_{\alpha i} = \angle O^{/}OC - \angle AOC \tag{7}$$

In figure 5b it is seen that OOC is equal to the difference of inclination angle of OC and OO lines to OX-axis which can be expressed by the relation:

$$\angle O^{/}OC = \operatorname{arctg}\frac{y_i + \delta_{yi}}{x_i + \delta_{xi}} - \operatorname{arctg}\frac{y_i}{x_i} \tag{8}$$

In its turn, angle AOC at the known values of sides AO, OC and AC of triangle AOC is determined from geometrical relations as follows:

$$\angle AOC = \arccos\frac{\sqrt{(AO)^2 + (OC)^2 - (AC)^2}}{2 \times AO \times OC} \tag{9}$$

Let's substitute in this relation the values of sections $AO = \sqrt{x_i^2 + y_i^2}$, $OC = \sqrt{(x_i + \delta_i)^2 + (y_i + \delta_{yi})^2}$, $AC = 0{,}5S_i$, and obtain:

$$\angle AOC = \arccos\frac{4(x_i + \delta_{xi})^2 + 4(y_i + \delta_{yi})^2 + 4(x_i^2 + y_i^2) - S_i^{\,2}}{8\sqrt{(x_i + \delta_{xi})^2 + (y_i + \delta_{yi})^2} \times \sqrt{x_i^2 + y_i^2}} \tag{10}$$

Based on relation (7), taking into consideration formulae (9) and (10), limit angular displacements $E_{\alpha I}^{B(H)}$ should be determined as follows:

$$E^{B(H)}_{\alpha 1} = \operatorname{arctg}\frac{y_i + \delta_{yi}}{x_i + \delta_{xi}} - \operatorname{arctg}\frac{y_i}{x_i} \pm Q \tag{11}$$

$$Q = \arccos\frac{4(x_i + \delta_{xi})^2 + 4(y_i + \delta_{yi})^2 + 4(x_i^2 + y_i^2) - S_i^{\,2}}{8\sqrt{(x_i + \delta_{xi})^2 + (y_i + \delta_{yi})^2} \times \sqrt{x_i^2 + y_i^2}} \tag{12}$$

The obtained relations for determining limit linear and angular displacements depending on the real values of geometrical characteristics of a single coupling with a gap will permit, using relation (4) to calculate basic elements setting errors in the plane of the formed joints with bearing surfaces, as well as using probabilistic statistical studying methods to establish parameters of these errors scattering. For the probabilistic-statistical analysis of setting errors it is necessary to establish preliminary the laws and parameters of intrinsic errors distribution.

Conclusions:

1. For real assembly processes the set element displacements described by relations (2) and (3) are related to the conditions of the basic element aiming to anchor bolts. Therefore the aiming error is no less than the value of gaps in "bolt-hole" couplings.

2. The analysis of the revealed theoretical layouts of the set element displacements in the plane of the formed bolt joints shows that parameters of displacements distribution differ significantly from the similar parameters obtained when designing dimension chains with gap elements. Besides, changing parameters of the element displacement distribution is oriented to the side of increasing these elements setting accuracy which proves the presence of accuracy reserves and reducing assembly processes labor intensity.

3. The obtained relations for determining limit linear and angular displacements depending on the real values of geometrical characteristics of a single coupling with a gap will permit, using relation (4) to design the basic elements setting errors in the plane of the forms joints with bearing surfaces.

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КЕРГІШ БЕКІТПЕЛЕРДІҢ БІР БОЛТТЫ ҚОСЫЛЫСТАРЫНДАҒЫ ШЕКТІ ЫҒЫСУЛАРДЫ АНЫҚТАУ

Аннотация. Н. Н. Стрелецкий әдістемесі бойынша зазор – буындары бар өлшем тізбектерінің жылжу жүктемелерін қабылдайтын болтты қосылыстарды есептеудің қазіргі инженерлік әдістемесін және басқа авторларды қолдану бір болтты қосылыстарды құрастыру дәлдігін талдау үшін де, көпболтты қосылыстар үшін де бірдей.

Мақалада саңылаумен жанасу санының көп болтты қосылыстарды құрастыру дәлдігіне әсері қарастырылған. Бастапқы қателіктерді, атап айтқанда бір бұрандамамен қосылыстарды құрастыру кезінде туындайтын шекті ығысу және көп болтты қосылыстардың жиналатын элементтерінің өзара бағдарлануының дәлдігін анықтайтын қателіктерді үлестіру функциясының өзара байланысының сипаты белгіленген. Ығысу күштері міндетті түрде шекті мәндерге жете бермейтін элементтердің ығысуын тудыратын неғұрлым күрделі жағдай үшін түзілген қосылыстардың жазықтығында негізгі элементтерді орнату қателіктерінің пайда болуының теориялық схемалары қарастырылады. Құрылған болт қосылыстарының жазықтығында орнатылған элементтердің ығысуының пайда болуының анықталған теориялық сызбаларын талдау, ығысудың таралу параметрлері байланыс-саңылаулары бар өлшемді тізбектерді есептеу кезінде алынған ұқсас параметрлерден айтарлықтай ерекшеленетінін көрсетеді.

Түйін сөздер: субель, өзінен анкерленетін болт, кергіш бекіткіш, "болт-тесік" түйіндемесі, сызықтық және бұрыштық ығысу, көпболттық қосылыс, қондырғының қателігі.

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ОПРЕДЕЛЕНИЕ ПРЕДЕЛЬНЫХ СМЕЩЕНИЙ В ОДНОБОЛТОВЫХ СОЕДИНЕНИЯХ РАСПОРНЫХ КРЕПЛЕНИЙ

Аннотация. Использование существующей инженерной методики проектирования болтовых соединений, воспринимающих сдвиговые нагрузки размерных цепей с зазорными элементами по методике Н. Н. Стрелецкого и других авторов, дает сходные результаты как для анализа точности одиночных болтовых соединений, так и для анализа точности многоболтовых соединений.

В статье рассмотрено влияние количества сопряжений с зазором на точность сборки многоболтовых соединений. Установлен характер взаимосвязи функций распределения исходных погрешностей, а именно предельных смещений, возникающих при сборке соединений с одним болтом, и функциями распределения погрешностей, определяющих точность взаимной ориентации собираемых элементов многоболтовых соединений. Рассмотрены теоретические схемы образования погрешностей установки базовых элементов в плоскости образуемых соединений для более сложного случая, когда сдвигающие силы вызывают смещения элементов не обязательно достигающих предельных значений. Анализ выявленных теоретических схем образования смещений устанавливаемых элементов в плоскости образуемых болтовых соединений показывает, что параметры распределения смещений существенно отличаются от аналогичных параметров, получаемых при расчете размерных цепей с звеньями-зазорами.

Ключевые слова: дюбель, самоанкерующийся болт, распорный крепеж, сопряжения «болт-отверстие», линейные и угловые смещения, многоболтовое соединение, погрешность установки.

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