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THE USE OF THE FRICTION-MOVABLE BRACES FOR DESIGNING THE SEISMIC PROOF STRUCTURES WITH PREDETERMINED PARAMETERS OF ULTIMATE CONDITIONS

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ABSTRACT

The use of the friction-movable braces for designing the seismic proof structures with predetermined parameters of ultimate condition to reduce of seismic loads. Under the apparent simplicity of the decision suggested its practical realization is troublesome. These difficulties are connected with the instability of the friction forces in the brace caused by fretting, scoring and melting of the contacting sufaces in the process of moves. To provide the work stability of the friction-movable braces became the main problem of investigations presented.

The method of investigations included the testing of the full-scale braces; construction of the mathematical apparatus for describing the FMB operation (FMB - friction-movable braces), calculation of parameters, which specify the operation of the braces; constructing the diagrams of FMB deformation and analysis of seismic stability of the structures with FMB.

KEYWORDS

Friction-movable braces (FMB), high-strength bolts, oval holes, friction forces, testing, calculation, use.

INTRODUCTION

The modern approach to the designing of the structures, being subject to seismic loads proceeds from the purposeful creation of ultimate conditions of the structures. In literature such approach was named as the designing of the structures with predetermined parameters of ultimate conditions. In addition, the nodes, in which the easy-rebuilding damages of the elements can arise due to extremal loads, are created in the structure.

As the result of these damages the normal operation of the structure is discrupte, however its collapse is excluded, in other words no collapse is possible. To realize this principle of designing the FMB have been suggested.

By FMB is meant the connection of metalworks with the help of high-strength bolts the different of which is that the holes for bolts in details being connected are fulfilled as oval along the direction of the of extremal loads action. At extremal loads there is a mutual move of details being cnennected for magnitude up to 3-4 diametrs of the high-strength bolts being used. The operation of such braces has a whole set of peculiarities and considerably influences upon the of the structure as a whole. Here it turns out to be possible to lower expenses for the reinforcement of the structure.

The FMB were suggested in Russia in 1980-90 and are protected by the few author's licenses (Authors license of the USSR N 1143895, 1168755, 1174616). However, the designing and the calculation of such braces caused serious difficulties. The first testing of FMB ascertained that the class of braces being considered didn't provide, in general case the stable operation of the structure. In the process of move the seize of the brace, the melting of contacting surfaces etc. are possible. In a number of cases there occurred the breakage of the bolt head. Up today there is no general theory of FMB, even for one-bolted brace. The situation retards the introduction of the progressive braces into the building practic.

The aim of investigations proposed is creation of the theory of the FMB operation and practical methods of their calculation, as well as the methods of calculation of the structures with FMB and technical solutions of braces nodes of the building structures with FMB.

INITIAL PREMISES FOR ELABORATION OF THE METHODS OF FMB CALCULATION

Initial premises for elaborating the methods of FMB calculation are experimental investigations of one-bolted lapping braces. The analysis of the produced diagrams of deformation allowed to distinguish there 3 characteristic stages of operation, showed in Fig.1.

In the first stage the load T doesn't exceed the bearing strength of the brace [T] designed as for usual brace on friction high-strength bolts.

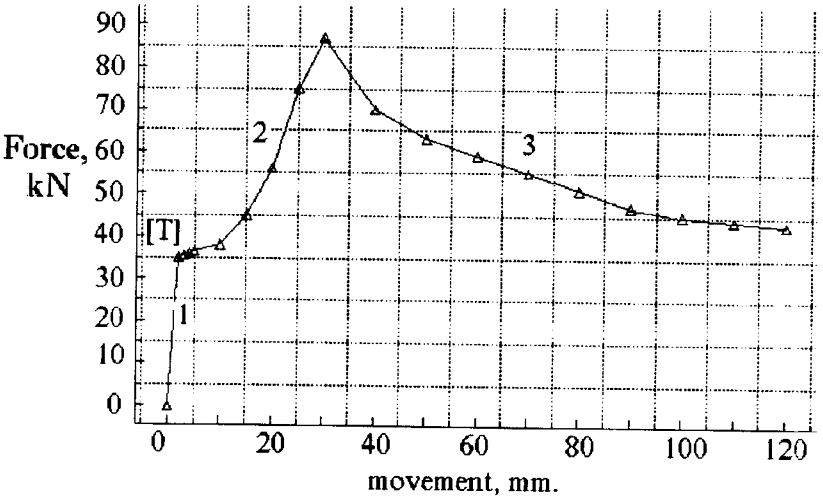

Fig.1. Characteristic stages of FMB operation

In the second stage T>[T] the friction forces along the contacting surfaces of the elements being connected at the unmovable high-strength bolts washers are overcome. In this case, owing to the deformation of the bolts the friction forces are growing along all the surfaces of the contacts.

In the third stage one of the washes slide out from its site and the further mutual displacement of the connecting elements takes place.

During the move the intensive wear being accompanied by the fall of the bolt tension and as the result the fall of the brace bearing strength is observed in all contact pairs.

When teasing the following cases of FMB failure were observed:
- considerable mutual displacements of the details being connected in the results of which the bolt sets against the edge of the oval hole and ultimately shears, itself.
- break-off of the bolt head due to minor-cycle fatigue.
- considerable plastic deformations of the bolt resulting in its irreversible elongation and exclusion from operation at "reverse motion" of the brace elements.
- considerable wear of contact surfaces leading to the loosening of the bolt and decreasing of the FMB bearing strength.

The results registered are of double interest for describing of the FMB operation. On the one hand, for designing the efforts and displacements in the elements of the structures with FMB it's important to specify the diagram of brace deforming. On the other hand, it's necessary to determine the opportunity of transition for FMB operation to ultimate condition.

When describing the diagram of deforming the fact of intensive wear of the brace frictioning elements that leads to the fall of tension forces and bolt bearing strength, seems to be most essential. This effect must define operations of both joint and lap FMB. For the lap FMB an extra growth of tension forces due to the bolt deformation is also important. For assess the transition of the brace to the ultimate condition the following checks are necessary:
a) for ultimate wear of the contact surfaces;
b) for the bolt strength and strength of sheets being connected for crush in case of depleting of the FMB u_o clearance depleting;
c) for the structure bearing strength in case of impact in the moment of FMB clearance closure;
d) for the bolt body strength for breakage in the moment of move.

Taking into account the well-known investigations (Albert I.U. et.al., 1988), the checks b) and c) are substituted by the check that confines the FMB displacements u by the size of the factual clearance in the brace u_o.

The solution of the problem about the wear of the FMB contact surfaces and move in the brace must be based on the specifying of the brace deformation diagram which represents the dependence its bearing strength T on the move in the brace S. Therefore get the plot T(s) is the basic for designing the methods of FMB calculation and structures with such braces.

GENERAL EQUATION FOR DETERMING THE FMB BEARING STRENGTH AND ITS SOLUTION.

The first stage of the FMB operation doesn't differ from operation of conventional frictional braces. On the second and the third stages of operation the brace bearing strength changes due to the changing of the bolt tension. In its turn the bolt tension is determined by its deformation and by the wear of frictioning surfaces of block sheets under their mutual displacement. For theoretical describing of deformation diagram we will use the classical theory of wear, according to which the wear speed V is proportional to the force of normal pressure (of bolt tension) N:

$$V = K \cdot N, \tag{1}$$

where K - wear coefficient,

$N = N_o - a \cdot \Delta + \Delta N_1 - \Delta N_2$;

N_o - initial tension of the bolt; $a = EF/l$ - bolt stiffness; l - bolt length, EF - its linear of stiffness; $\Delta N_1 = \chi \cdot f(s)$ - increase of the bolt's tension in the result of its deformation; $\Delta N_2 = \varphi(z)$ - reduction of bolt tension in the result of its plastic deformations; s - quantity of move in the brace; Δ - wear in the brace.

For jointing braces both components $\Delta N_1 = \Delta N_2 = 0$. When neglecting the change of the speed of the move, this appearing to be permissible for conditions of the experiments being conducted, we get the following equation:

$$\Delta' = k \cdot N \tag{2}$$

where $\Delta' = \frac{d\Delta}{ds}$; $k = \frac{K}{V_m}$; $Vm = \frac{ds}{dt}$ - average speed of the move.

Solution to the equation can be presented as follows form:

$$\Delta = N_o a^{-1}\left(1 - e^{-kas}\right) + k\int_o^s e^{-ka(s-z)}\left[\chi \cdot f(z) - \varphi(z)\right]dz \tag{3}$$

For joint braces the general integral is simplified, because in this case the functions f(z) and φ(z) in (3) reduces to 0. In view of the mentioned above the use of integral (3) allows to get the following formular for determining the wear amount Δ:

$$\Delta = (1 - e^{-kas})\, N_o\, a^{-1} \tag{4}$$

and brace bearing strength is determined by the formular:

$$T = T_o\, e^{-kas}, \tag{5}$$

where $T_o = N_o \cdot f$, f - friction ratio.

As can be seen from the formular derived, the relative bearing strength of the brace $K_T = T/T_o$ is determined only by two parameters : by the wear coefficient k and by the bolt stiffness in tension a. The calculations show that with the increase of the block thickness the influence of the sheets wear upon the bearing strength of the braces is being reduced. In a whole the decrease of the bearing strength of the braces at real amounts of move s is of 25-30% for the joint braces. Such fall of tension is to lead to the growth of mutual displacements of details being connected and this fact must be taken into account in engineering calculations.

For the lapping FMB the general solution is determined by the form of the function f(s) and φ(s). The function f(s) depends on the bolt's the elongation due to the bending of its axis. Considering the bolt as a geometrically nonlinear bar, it is possible to can be show that the function f(s) can be represented as:

$$f(s) = \chi \frac{s^2}{l}\left[1 - \eta(s - s_o)\right], \tag{6}$$

where η - heviside's unit function.

For the function φ(s) the following relation is used:

$$\varphi(s) = \left[N_{pl} + \left(N_{fl} - N_{pl}\right) \cdot \left(1 - e^{\alpha(s - S_{pl})}\right)\right] \cdot \left[1 - \eta(s - s_o)\right]\eta\left(s - S_{pl}\right), \tag{7}$$

where N_{pl} - bolt tension under which the plastic bolt deformation appears, N_{fl} - dolt yield strength.

The brace bearing strength is determined here by the expression:

$$T = T_o - f_v \cdot a \cdot \Delta \tag{8}$$

where the amount Δ is defined by the formular:

at $s<S_{pl}$, $$\Delta = \Delta^{I}(s) = \frac{N_o}{a}\left(1-e^{k_1 as}\right)+\frac{\chi}{al}\left[s^2-\frac{2}{(k_1 a)^2}\left(1-e^{k_1 as}\right)\right];$$

at $S_{pl} < s < S_o$,

$$\Delta = \Delta^{II}(s) = \Delta^{I}(S_{pl}) + k_l\left[\frac{N_{fl}}{k_l a}\left(1-e^{k_l a\left(S_{pl}-s\right)}\right)-\frac{N_{fl}-N_{pl}}{k_l a-\alpha}\cdot\left[e^{\alpha\left(S_{pl}-s\right)}-e^{k_l a\left(S_{pl}-s\right)}\right]\right];$$

at $s > S_{pl}$, $$\Delta = \Delta^{III}(s) = \Delta^{II}(S_o) + \frac{N(S_o)}{a}\left[1-e^{-k_2 a(s-S_o)}\right];$$

$$N(S_o) = N_{pl} - \left(N_{fl} - N_{pl}\right)\left[1-e^{-\alpha(S_o-S_{pl})}\right] - a\Delta^{II}(S_o)$$

f_v - the coefficient of friction which depends in general case on the move speed v. We used the most common dependence of friction coefficient upon the:

$$f_v = {}^{f}\!/_{(1-k_v v_m)},$$

where k_v - constant coefficient.

The dependence suggested contains 9 indeterminate parameters k_1, k_2, k_v, S_o. S_{pl}, α, f, N_o, χ. These parameters are determined from the data of the experiment.

By means of their variation on the lattice of possible values and for each nine parameters values the quantity of residual between calculation and experimental diagram of deformation was calculated according to the method of least squares, the residual was being summed with respect to the marked points of experimental diagram.

The characteristic diagram of FMB deformation which was experimentically obtained as well as the and theoretical diagram being correspondent to the former are presented in Fig.2. A correlation of calculated and full-scale data points that parameters a good coincidence of full-scale and calculated diagrams of FMB deformation by selection of FMB. The divergence of diagrams at their final section is conditioned by abrupt fall of the move speed before the stop, which is not taken into account within the scope of the suggested theory of FMB calculation.

It should be noted that in most cases the values of FMB parameters show a considerable spread. This fact hampers the use of the one-bolted FMB. At the same time, the transition from the one-bolted braces decrease the spread in parameters of deformation diagram.

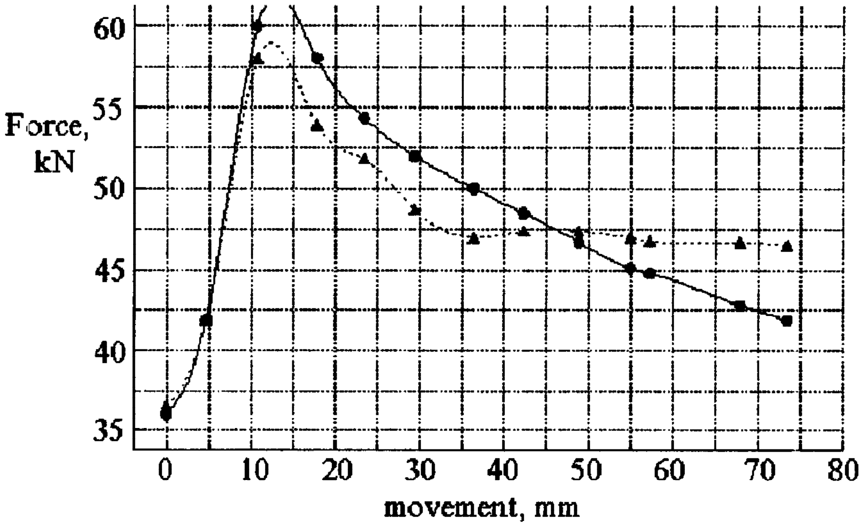

Fig.2. Dependences T(s)

● - theoretical data;
△ - expirience data.

For the multi-bolt jointing braces the following design formulae to estimate the bearing strength are obtained:

$$T = nT_O \frac{sh\left(sa\sigma_k\sqrt{3}\right)}{sa\sigma_k\sqrt{3}},$$

where n - number of bolts;
T_O - bearing strength of one-bolt brace;
σ_k - mean square devation of wear coefficient.

PECULIARITIES OF DESIGNING OF FMB AND STRUCTURES WITH SUCH BRACES

The results of investigations allow to state a number of general demands to designing FMB and of structures with such braces. The following belongs to the number of these demands.

1. When designing the FMB one should reduce the friction coefficient of rubbing pairs providing the necessary friction at the expense of increase of diameter and number of bolts.

2. For improving the FMB efficiency it's necessary to decrease the spread of quantity of the initial bearing strength of the brace at the expense of increasing the quality of working of the ports being connected.

3. When calculating the structures with FMB the assessment of the following ultimate conditions is necessary:
- absence of moves in FMB at the operational loads;
- restriction of maximum accelerations of the structure at the extremal load;
- restriction of maximum replacements in FMB by the size of the total length of the half-ovals of the holes for bolts.

4. Other conditions being equal, one should give preference to the use of thick blocks and increase of number of bolts in the brace, because in this case the spread of statistic characteristics of FMB decreases and the influence of the friction degradation upon the brace bearing strength also decreases.

5. In the result of mass calculation of the structures with FMB the possibility of the optimal setting of the brace on friction, that minimizes the maximal accelerations in structure as well as two possible modes of structure movement at "in phase" and opposite phase displacements of the elements being connected are determined.

REFERENCES

Albert I.U., Kaufman B.D., Savinov O.A., Uzdin A.M.(1988). Seismoisolating foundations of NPS RR. - Moscow: Inforenergo.