

# Stress condition of the elements of support blocks of fixed offshore platforms and resource evaluation of them

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**Abstract.** The article analyzes the factors causing the stress state of the support blocks of fixed offshore platforms (FOPs). The data on the wind-wave regime of the Subbotinsky field of the Black Sea are analyzed, the parameters are determined and the cycles of wind-wave loads acting on the platform are systematized. Using the StructureCAD software package, the values of the effective equivalent stresses were determined from the weight of the structural elements of the FOP, the installed technological equipment, the floating forces of the aquatic environment and wind-wave loads under various conditions of the orientation of the wave beam with respect to the support block. Various design options for FOPs are analyzed and the problem of finding “zero elements” is solved. The proposed solutions will allow developing a comprehensive methodology for assessing the stress state of the support block of the FOP. Besides, for the purpose of determining the resource of the elements, the values of the equivalent stresses of the columns, horizontal belts and braces of the support block of the FOP are determined. The example of calculating the resource of platform elements is given.

## 1. Introduction

### 1.1. Fixed offshore platforms

In modern conditions, significant volumes of oil and gas are produced in offshore fields. This production is carried out using fixed offshore platforms (FOPs), which have a different design. The fixed offshore platforms of the truss type are widely used, which are used in production at various depths. These platforms are pipes of different diameters welded together (Figure 1).



**Figure 1.** Fixed offshore platform



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These platforms are affected by wind, wave and other loads, which cause them to vary in direction and magnitude of stress. The methods for calculating the values of these loads are well described in the normative and technical documentation and specialized literature. The purpose of this article is to study the factors affecting the stress state of the support block of the FOP and their numerical estimate.

### *1.2. Operating environment of fixed offshore platforms*

Most elements of the FOP support block are in a difficult-stressed state, often subjected to the combined action of bending, stretching, compression, and torsion. The authors of the study analyzed 8 reports on inspections of this type of platforms located on the Black Sea shelf, which unequivocally indicated that the greatest damage to the platform was found in the variable wetting zone, located from (below) -10 meters from sea level and (above) +14 meters from sea level. This zone is officially recognized, taking into account the possible once every 100 years, an extreme wave height of 13.9 m (1982 storm). However, in fact, as follows from [1-5], the calculations performed by the authors showed that the wave height that directly causes fatigue failure does not exceed 6.3 meters. And only the influence of extreme winds with a speed of more than 49 m/s can cause a wave height of 13.9 m. The author conducted an analytical study, which showed that in the elements of the underwater part of the platform there are high voltages, due to both the weight characteristics of the platform and the action of bending and torques from the wind-wave load (WWL). In the absence of WWL, these voltages are static and act in columns of FOPs along their axes. If we schematically consider the column as a beam with one pinched and one cantilever end, then we can see that the maximum stress values (of the order of 173 MPa) arise both at the point of conditional application of the load and at the points where the columns are fixed to the ground (about 250 MPa). From this it follows that the maximum total values of stresses from static and dynamic loads will be achieved in the areas of fastening to the ground. However, this is true only for columns. For horizontal elements, maximum stresses arise due to the action of wave, ice and other dynamic loads, which reach their maximum values in the zone of variable wetting. For braces, both of these provisions are true, because in addition to dynamic loads, part of the load from the weight of the structure is redistributed on them.

Therefore, the zone of greatest stress for the braces can be identified only as a result of the calculation. To study the stress state of the FOP support block, it is necessary to determine the wind parameters, since the parameters of the wave action (wavelength, its height and period) are dependent on wind speeds. Using the data from the site meteo.ua, it was found that in the area of the platform, there are winds that can be classified by speed:

**Table 1.** Characterization of wind exposure in the area of installation of FOPs

Wind speed	The average value of the total number of wind hours of a given speed per year	Duration of one cycle, in hours	The number of cycles per year
10	1155	21	55
15	1040	20	52
20	153	17	9
25	36	12	3

In addition to the given values, extreme values of the wind speed are also possible, causing a wave action with different values of security, which leads to an increase in wave height, and as a result, the magnitude of the wave load. As an example, we give the parameters of the waves of the Subbotinsky oil and gas field, with a maximum wind speed of 49 m/s:

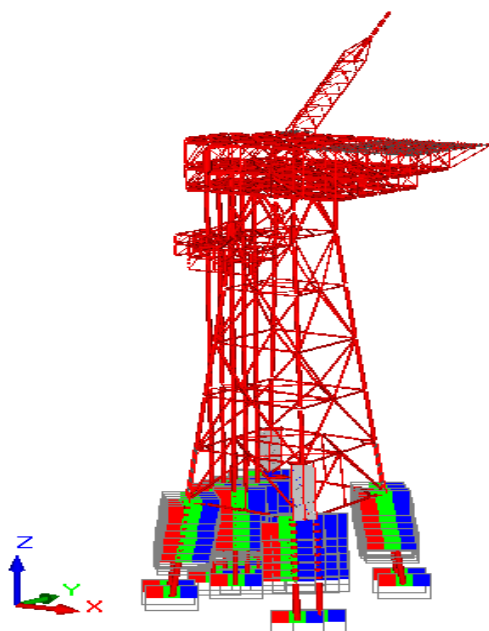
**Table 2.** Characteristics of waves at Subbotinskoye field according to the project

Wave elements	Wind direction, bearing							
	W	S-W	S	S-E	E	N-E	N	N-W
$\bar{h}$ , M	5.2	6.3	6.3	6.3	4.8	2.8	2.3	2.9
$h_{1\%}$ , M	11.7	13.8	13.9	13.8	10.8	6.5	5.3	6.8
$\bar{\tau}$ , c	7.6	8.5	8.3	8.4	7.3	5.2	4.7	5.5
$\bar{\lambda}$ , M	88	108	105	107	81	42	34	45

## 2. Materials and methods

### 2.1. Stress factors in elements of offshore platforms

Let us analyze the factors causing the stress state of the support block. All the elements of the support block can be conditionally divided into columns, horizontal elements and braces. If we analyze the support columns, then in the absence of wind-wave action, significant stresses in these racks are created precisely by gravity from their own weight, the weight of the equipment, sea fouling and other weight factors. In this case, one should take into account the specific feature inherent in all hydraulic structures, namely the buoyancy force on elements immersed in the aquatic environment [1-20]. There are also columns with concrete filling the in-pipe space, resulting in a redistribution of stresses. To take this feature into account in the SKAD software package, on which the stress state of the platforms was simulated, a special module was used to calculate the shotcrete rods. The author investigated designs of both rectangular and pyramidal types (Figure 2 (a) and Figure 2 (b)). In addition to compressive forces due to gravity, various loads (wave, wind, etc.) act on the structural elements of the FOP in the horizontal direction. Note that for vertical elements it is possible to represent the wave load as a concentrated force with a certain coordinate measured from the sea surface, or as an unevenly distributed load.

**Figure 2 (a).** Pyramidal platform**Figure 2 (b).** Pyramidal platform

We turn to the consideration of horizontal belts. As calculations showed, horizontal belts in most cases are loaded much less than columns and braces. Only in the zone of variable wetting, the values of these stresses reach their maximum values, close to the values of the maximum stresses in the columns and braces. The load pattern for elements arranged horizontally also changes. In the absence of WWL, weight loads will no longer play such an important role in the formation of the element's stress state as in the case of a column or a brace. Moreover, from the side of the columns, depending on the direction of the wave beam, both torque and bending moments can form, which in some cases can act simultaneously.

The analysis showed that all the forces and loads acting on the braces of the support block of the SME are in many respects similar to the loads of horizontal elements, except for the presence of significant longitudinal forces due to gravity. Therefore, methods for assessing the stress state for columns and horizontal elements are similar to methods for assessing the stress state of braces.

## 2.2. *Methods for estimation the stress state of offshore platforms*

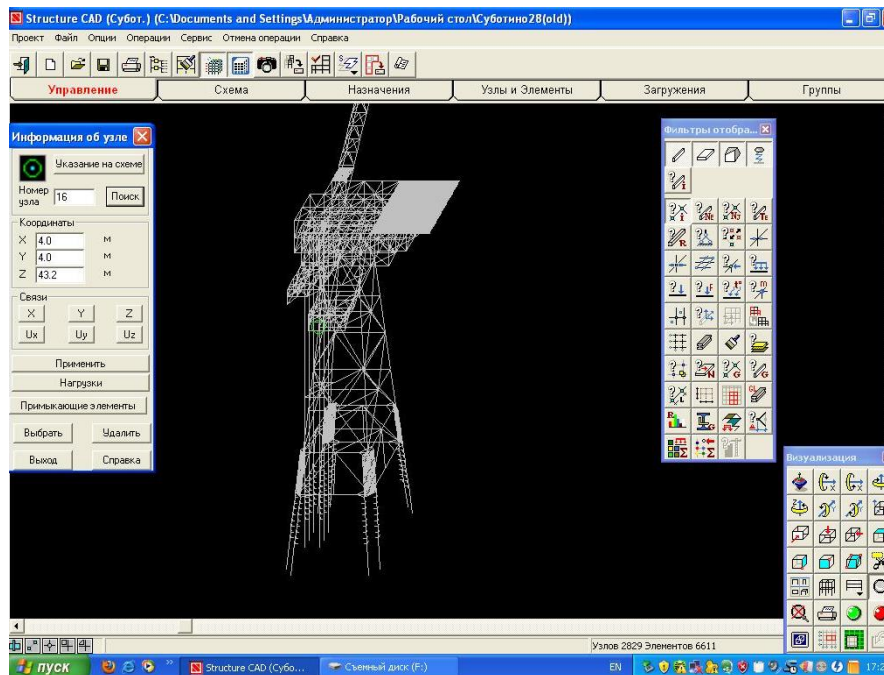
The important issue is the assessment of the stress state of the platform. According to the author, it is advisable to solve this problem with the help of modern theories of strength, which allow finding the values of "equivalent" stress. To solve this problem, we select around a point of the structural element of the support block of a parallelepiped with edges of infinitely small length. In the general case, normal and tangential stresses can act on the faces of this elementary parallelepiped. The set of stresses at various sites passing through a point is called the stress state of the material at the point. It is proved that it is possible to arrange the box in such a way that only normal stresses remain on its faces. Such faces are called the main areas, and the stresses on them - the main stresses. The largest principal stress is denoted by  $\sigma_1$ , the smallest by  $\sigma_3$ , and the intermediate by  $\sigma_2$ . The complicated stress state of the platform is described in the form of stress equivalent to simple tension, which is called equivalent  $\sigma_{ek}$  and is calculated by the formula:

$$\sigma_{ek} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}, \quad (1)$$

Where:  $\sigma_1, \sigma_2, \sigma_3$  are the main stresses.

Let us consider the stress state of the support block of a fixed offshore platform using the example of the FOP installed at the Subbotinsky field. The practice of designing and operating such platforms shows that taking into account the mutual influence of various platform elements is an extremely difficult task. To analyze the stress state of the platform, a computer model was built in the StructureCAD software package (Figure 3).

It is more convenient to analyze the stress state by calculating the equivalent stress values for each element. To assess the stresses arising in the platform elements, the model was loaded with loads affecting its fatigue failure, namely, the following were set: loads from dead weight, from the weight of the equipment and sea fouling, the buoyancy force of the aquatic environment (combination of K1 loads) and wind load wave exposure (WWL). Moreover, to take into account the mutual influence of the elements, the direction of development of the wind-wave load was set both along the X axis (combination of loads K2) and in the direction at an angle of 45° to the axis X (combination of loads K3). The magnitude of the wave load was chosen corresponding to the wave action of 1% coverage. Structurally, the platform is a truss structure of pipes, and has five sections, each of which is approximately ten meters high.



**Figure 3.** Model of the platform in the StructureCAD software package

### 2.3. Method for estimating the resource of offshore platform elements

To assess the resource of the elements, it is necessary to know its stress state, which will allow dividing the stresses caused by loads of different magnitude into amplitude variable voltage units for one year of operation [17-20]. The loading unit consists of several stages of loads, each of which causes alternating stresses, which can be characterized by the amplitude of the alternating voltage  $\sigma_{ai}$ , the number of repetitions of this amplitude in stage  $v_{ai}$  and the frequency of application of the load  $v$ . With the number of loading blocks  $\lambda$ , the number of cycles of stress amplitude repetitions  $\sigma_{ai}$  for the entire operating time will be:

$$n_i = \lambda v_{i\sigma} \quad (2)$$

If the number of cycles to failure along the fatigue curve at stress amplitude  $\sigma_{ai}$  equals  $N_i$  cycles, then at this amplitude the structure receives a fraction of damage equal to  $n_i/N_i$ . In this case, the destruction under block loading will occur when the sum of the values of the relative damage becomes equal  $a_p$  and the condition of destruction will take the form:

$$\sum_{i=1}^g (n_i/N_i) + \sum_{i=1}^k (n_i/N_i) = a_p \quad (3)$$

$$(\sigma_{ai} > \sigma_{Rk}) \quad (\sigma_{ai} < \sigma_{Rk})$$

where  $a_p$  – the critical degree of damage to the material corresponding to the moment of fracture or crack initiation and is calculated by the formula:

$$a_p = \sum_{i=1}^k (\sigma_{ai}/\sigma_{max}) t_i, 0.2 \leq a_p \leq 1 \quad (4)$$

where  $k$  - number of block steps;  $\sigma_{max}$  – maximum amplitude in the loading unit;  $t$  - the parameter calculated for all stages of the block according to the formula:

$$\lambda = \frac{a_p}{\sum_{i=1}^g \frac{v_i \sigma_{ai}^{m_1}}{\sigma_{Rki}^{m_1} N_{Gi}} + \sum_{i=1}^k \frac{v_i \sigma_{ai}^{m_2}}{\sigma_{Rki}^{m_2} N_{Gi}}} \quad (5)$$

$$\begin{aligned} & (\sigma_{ai} > \sigma_{Rk}) \quad (\sigma_{ai} < \sigma_{Rk}) \\ & \sigma_a^{m_2} N = \sigma_{Rk}^{m_2} N_a \quad \text{if } \sigma_a < \sigma_R \end{aligned} \quad (6)$$

Where: the values are the same as in the formulas (2-4).

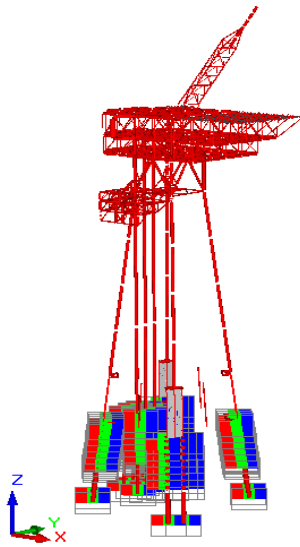
### 3. Discussion

#### 3.1. Equivalent stresses in the elements of the offshore platform with various loading combinations

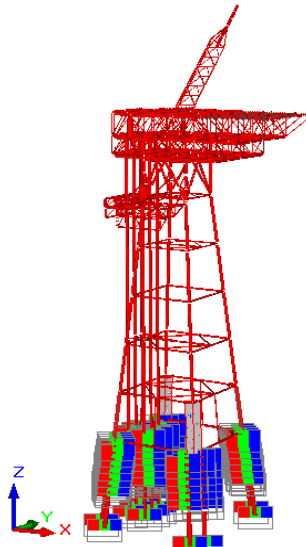
As a result of a study on a computer model performed by StructureCAD, the following results were obtained under the condition of a wave of 1% security. An analysis of the columns of the support block of the FOP shows that the maximum equivalent voltage (EV) values that occur in the columns of the bottom section (1 section) with an external diameter of 720 mm and a wall thickness of 20 mm appear when exposed to a wind-wave load at an angle of 45 degrees and is 250 MPa. In the absence of WWL, the voltage is 45MPa. This is proved by the fact that stresses in the column are created not only from weight factors, but also from the wind-wave action, as a result of which significant bending and torque moments appear. In the second section, the maximum voltage also occurs with a wind-wave load at an angle of 45 degrees and, slightly differing from the bottom, is 242MPa, and in the absence of a wind-wave load of 43MPa.

In the next third section, the maximum voltage value occurs under the same conditions as the first two sections, but is already much smaller value of 115 MPa. In the absence of exposure, the voltage value is only 18MPa. This decrease in voltage is due to the fact that in this zone the weight loads are significantly redistributed to the braces. Further, for columns located in the zone of variable wetting, the maximum equivalent stresses increase, which is associated with the design feature of the platform and is caused by the design decrease in the cross-sectional area as a result of using pipes with a wall thickness of 25% less, as well as higher values of wind-wave load in this area. The maximum value of EV will be 197 MPa. In the atmospheric zone, the influence of the wave action is somewhat reduced, however, the action of bending and torques does not stop, and the maximum values of EV are 173 MPa. And in the absence of WWL, the magnitude of the EV reaches 51 MPa. Such an increase in the EV value is explained by the design features of the platform and is due to the fact that this element of the column is not inclined, like the previous ones, but vertical. In addition, in this area there are no braces. Analysis of the horizontal zones (HZ) of trusses made of pipes with a diameter of 420 mm and a wall thickness of 12 mm showed that the minimum stress state during WWL equal to 75 MPa is achieved in the HZ located in the bottom zone. Then, in the second zone, a slight increase in the equivalent stresses occurs. In the third zone, with an increase in WWL, the magnitude of stresses increases by 22%, the maximum values of the EV reach 92 MPa. Structurally, in the atmospheric and periodic wetting zones, the horizontal elements are made of 325 diameter pipes with a wall thickness of 12 mm, which reduces the cross-sectional area. However, in these zones the wave load reaches its maximum values; therefore, the stress values in these zones practically do not differ from the third zone. We turn to the analysis of electric power arising in the braces. In the absence of WWL, the EV values in the braces significantly exceed the similar values in columns and horizontal elements. This suggests that the effect of the combination of weight loads is significantly redistributed from the columns and the HE to the braces. The maximum values of EV are achieved with a combination of K2, maintaining a value of the order of 200 MPa, and gradually increasing with the increase in the action of WWL, reach their maximum in the zone of periodic wetting, and then significantly decrease in the atmospheric zone.

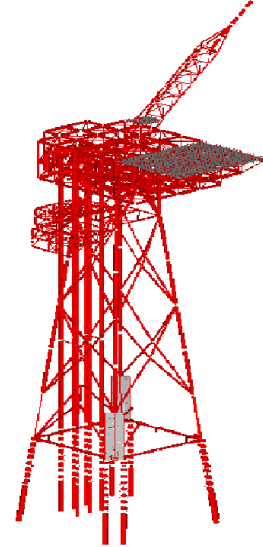
### 3.2. Study of “zero” platform elements



**Figure 4 (a).** Construction of the FOP SB, case 1



**Figure 4 (b).** Construction of the FOP SB, case 2



**Figure 4 (c).** Construction of the FOP SB, case 3

**Table 3.** Values of the equivalent stresses of the elements of the support block for various combinations of loading and various design solutions

The numbers of the sections of the support block <i>FOP</i>															
Load	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Values of equivalent stresses, MPa														
	Columns					Horizontal belts					Braces				
	$K_1$	$K_2$	$K_3$			$K_1$	$K_2$	$K_3$			$K_1$	$K_2$	$K_3$		
Values of equivalent stresses for case 1 (there are no braces and horizontal belts), MPa															
$K_1$	158	159	310	367	508	-	-	-	-	-	-	-	-	-	-
$K_2$	294	464	1092	1416	1573	-	-	-	-	-	-	-	-	-	-
$K_3$	2147	1283	1722	2673	2314	-	-	-	-	-	-	-	-	-	-
Values of equivalent stresses for case 2 (there are no braces), MPa															
$K_1$	273	247	243	365	409	11	275	261	266	16	-	-	-	-	-
$K_2$	1213	901	972	1213	1345	93	448	312	358	2	-	-	-	-	-
$K_3$	1771	1361	1375	2141	1954	290	2666	2658	2294	82	-	-	-	-	-
Values of equivalent stresses for case 3 (there are no horizontal belts), MPa															
$K_1$	72	55	26	30	90	-	-	-	-	-	79	32	75	127	51
$K_2$	313	275	138	143	186	-	-	-	-	-	287	252	229	392	28
$K_3$	450	405	203	211	123	-	-	-	-	-	235	23	306	256	60

The study of the support block of the FOP for the so-called “zero” elements, i.e. unloaded items is of considerable practical interest. Let us calculate the equivalent stress values for two cases: 1) there are no braces and horizontal elements in the support block (Figure 4 (a)); 2) only braces are absent in the support block (Figure 4 (b)); 3) only horizontal belts are absent in the support block (Figure 4 (c)). We develop computer models corresponding to the above three cases and calculate the maximum equivalent stresses. If we create a platform consisting exclusively of columns, then in the absence of WWL the stresses arising in them will not exceed the allowable voltage for steel 17G1S, of which the columns are



made, equal to 252 MPa. However, in the presence of WWL, both for load combinations K2 and K3, the voltage values significantly exceed the permissible voltage. For case No. 2, in which the columns are connected by horizontal belts, in the first and second sections of the columns there is even a slight increase in the EV values, which is explained by the appearance of additional torques. In the third, fourth and fifth sections there are a decrease in the magnitude of the EV. In this case, the stresses in the horizontal zones of the platform in the presence of WWL significantly exceed the level of permissible stresses. The situation is greatly changed by the introduction of braces, which redistribute a significant part of the load and reduce the acting stresses to almost the permissible level of stresses, even in the absence of horizontal belts. Thus, we can conclude that the braces play more important role in reducing the stress state of the platform than horizontal elements.

### 3.3. Stresses affecting the resource of offshore platforms

The establishment of stress parameters arising from the action of various wave loads is of great practical importance for establishing the resource of the elements of the support block. Table 4 shows the values of equivalent stresses obtained as a result of setting the WWL at various wind speeds and the main stages of the calculation on the example of a horizontal element with a diameter of 530 millimeters and a wall thickness of 15 mm located in the variable wetting zone.

**Table 4.** Calculation of the resource of horizontal elements of the support block of the FOP (main stages)

Wind speed	The value of the amplitude of the variable voltage $\sigma_a$ , from WWL	The number of repetitions of the i-th amplitude in the block	Relative running hours at the i-th voltage level	The product of the relative operating time at the i-th level by the ratio of the i-th amplitude to the maximum amplitude in the block
10 m/s	$\leq 22,5 \text{ MPa}$	-	-	-
15 m/s	23	544186	0,319902833	0,156548195
20 m/s	36	67583	0,039728943	0,03043068
25 m/s	47	14545	0,008550627	0,008550627

Let us calculate the equivalent stress amplitudes for the horizontal elements of the FOP support block made of 09G2S steel. Based on the data given in table 3, we calculate the resource of the horizontal elements of the support block of the FOP located in the zone of periodic wetting, in which the maximum alternating voltages act. Stress cycles under the wave action of 1% coverage were reduced to standard stress cycles under the action of the characteristic wave load at wind speeds of 10 m/s, 15 m/s, 20 m/s and 25 m/s. As the calculations showed, at a wind speed of 10 m/s the amplitude of the alternating voltage is less than 22.5 MPa, which allows it not to be taken into account in the calculations, because this magnitude of the amplitude does not have a damaging effect. At the wind speed of 15 m/s, variable stress amplitude of 23 MPa occurs, at a wind speed of 20 m/s variable stress amplitude is 36 MPa, at a wind speed of 25 m/s variable stress amplitude is 47 MPa. After calculating according to the method specified in Section 2.3, it was found that the durability of the horizontal element is approximately 21.3 years.

## 4. Conclusion

The author investigated the stress state of offshore platforms using the example of a truss-type platform located on the shelf of the Black Sea. Studies on a computer model showed that the maximum equivalent voltage (EV) values that occur in the columns of the bottom section (1 section) with an external diameter of 720 mm and a wall thickness of 20 mm appear when exposed to a wind-wave load at an angle of 45



degrees and is 250 MPa. In the absence of WWL, the voltage is 45MPa. This is proved by the fact that stresses in the column are created not only from weight factors, but also from the wind-wave action, as a result of which significant bending and torque moments appear. The problem of “zero” elements is investigated and the role of each element in the distribution of loads from the environment is shown. In the distribution of loads, a significant role is played by the braces, which redistribute a significant part of it, reducing stress both in the columns and in the horizontal elements. The method of calculating the resource is given, and the example of the column is used to calculate the resource of the pipe element, which established that the project resource is estimated at 21.3 years, which corresponds to the actual state of the structures.

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