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EXPERIMENTAL INVESTIGATIONS ON THE STRESS STATE IN THE BEARING STRUCTURE OF A SPECIAL WAGON TO TRANSPORT LIQUID IRON

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Abstract: *In order to increase productivity, to reduce energy consumption and for environmental protection, a special wagon intended for the transport of liquid pig iron, in steel mills, it was designed and manufactured. This wagon consists of an especial chamotted torpedo, with a capacity of 300 tons, rested, at each end, by means of a box beam, on two buggies, with four axles each one. To evaluate the mechanical behavior of this wagon during service, its prototype was investigated experimentally in terms of the stress and strain state. Due to difficulties encountered related to the long duration of loading and unloading time of the torpedo pot with liquid cast iron and due to very large dimensions of the carriage gauge, experimental investigations were performed on the torpedo pot and box beam models, manufactured at scale. The buggy structure was investigated on a special stand, set up in the laboratory of Strength of Materials Department of the Polytechnic University of Bucharest. The torpedo pot and box beam were investigated using two combined experimental techniques (brittle coatings technique and resistive strain gauge technique). Brittle coatings technique was used to identify the principal stresses directions, which then were applied electro-resistive transducers. Using strain gauge amplifiers the principal strains were measured, and principal stresses in measurement points were calculated. The results of these studies have led to changes of constructive solutions in the case of some substructures, contributing to increase the operational safety of the wagon.*

Keywords: stress state, box beam, bogie, strain gauge, brittle coatings

1. Introduction

The paper presents experimental investigations undertaken on the bearing structure of a special wagon designed and manufactured for transporting of liquid iron, in siderurgice mills. The wagon (Fig.1) consists of an especial chamotted torpedo pot (1), with a capacity of 300 tons, rested at each end, by means of a box beam (2), on two buggies (3), with four axles each one. Experimental investigations aimed to determine the stress and strain state in the torpedo pot, in the box beams and in the stringers of bogies. Due to the large sizes of the torpedo ladle and of the big difficulties related to loading and unloading with liquid iron, the stress state in the pot jacket of the torpedo ladle was determined by electro-resistive strain gauge technique on its model manufactured at scale 1:8. Box beams were investigated, also using electro-resistive strain gauge technique. In order to establish the highly stressed areas in which the electro-resistive transducers would be placed, a preliminary study, using brittle

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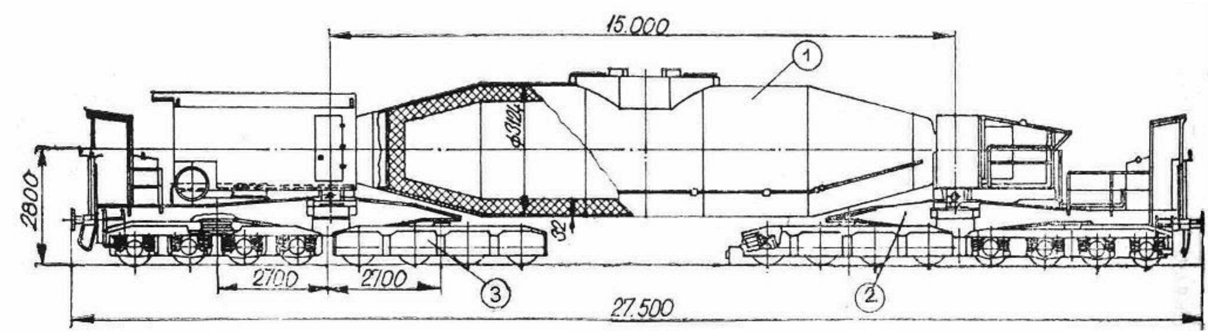

Fig. 1 The special vagon

coatings technique, was done on their model, manufactured at scale 1:8. Stress state in the stringers of bogies prototype was determined by using electro-resistive strain gauge technique, on an especially stand arranged in the testing hall in the Strange of Materials Department in Polytechnic University of Bucharest.

2. Stress State Analysis in the Jacket of the Torpedo Pot

Torpedo pot (Fig. 2) is a bearing structure consisting of a central cylindrical shell, having two conical shells at the ends. Central cylindrical shell is provided at the top with a window for loading and unloading of liquid metal. Inside the torpedo ladle can be filled with 300 t liquid irons when chamotte is new and with 365 t when it is worn. The model on which the experimental measurements were made, was made of sheet steel at 1: 8 scale, inside is not lined with masonry.

Loading of the model was made with steel grits, whose total weight was 700 kg. The steel grits mass modelled the mass of hot metal and chamotte.

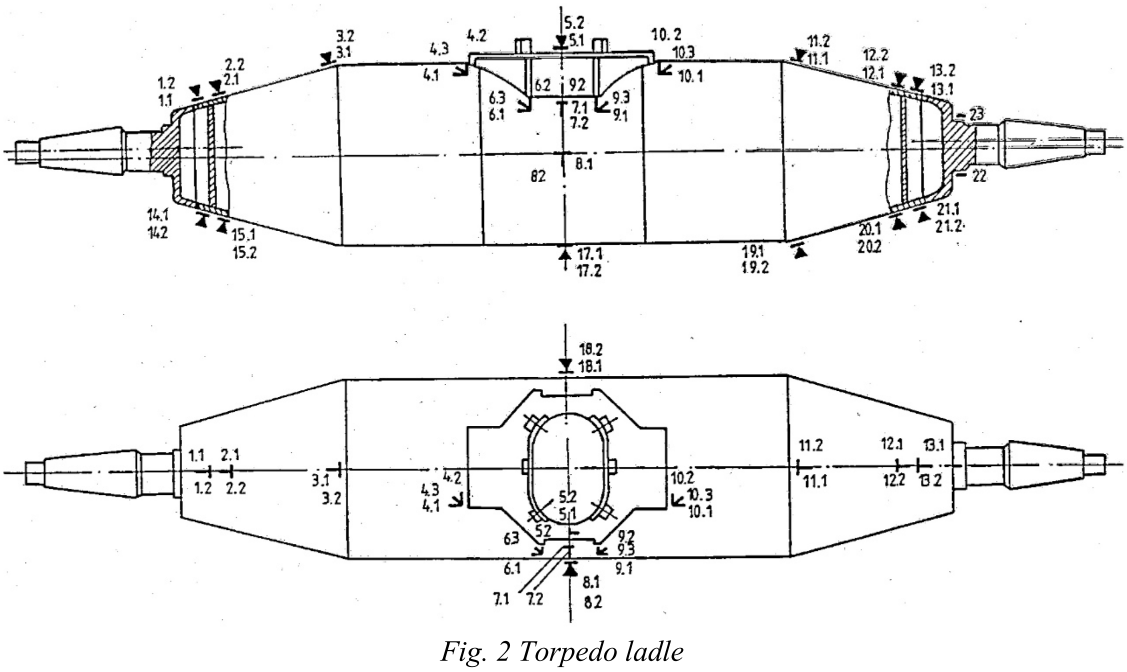

Fig. 2 Torpedo ladle

Experimental determinations consisted of strains measuring by using electro-resistive transducers applied in 23 points on the external surface of the model. Measurement points were located in the longitudinal plane, in the vertical symmetry plane, in the transverse plane of symmetry and in areas with concentrators. Were applied 17 rosettes on two directions, 4 rosettes on three directions at 45^0 and two simple transducers. The location of the transducers is shown in Fig. 2. The strains were measured for two loading cases:

a) at loading, respectively unloading of the torpedo pot, with steel grits with mass of 700kg, the model being with the longitudinal symmetry plane in vertical position;

b) the model loaded with steel grits rotated at 45^0. In the points, where rosettes were applied, on three directions, the principal strains were calculated with expressions (1). The principal stresses were calculated with relations (2).

$$\varepsilon_{1,2} = \frac{\varepsilon_a + \varepsilon_c}{2} \pm$$
$$\pm \frac{1}{\sqrt{2}} \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2} \quad (1)$$

$$\begin{cases} \sigma_1 = \dfrac{E}{1-\upsilon^2}\left(\varepsilon_1 + \upsilon\varepsilon_2\right) \\ \sigma_2 = \dfrac{E}{1-\upsilon^2}\left(\varepsilon_2 + \upsilon\varepsilon_1\right) \end{cases} \quad (2)$$

In these relations E is longitudinal modulus of elasticity and v is transversal contraction coefficient of material. After processing experimental data resulted that maximum stresses records at loading and unloading, at the upper part of the torpedo pot, in zone of charging and discharging aperture.

The maximum stress, for normal position, was recorded in the point 10 (σ=7,77 MPa), and for position rotated with 45^0 was recorded in the point 6 (σ = -9,77 MPa).

The transition from the model to prototype is made taking into account the scale coefficients for lengths k_l and forces k_f.

Taking into account that torpedo pot is loading in bending the stresses calculated with Navier relation are directly proportional with bending moment and inversely proportional with strainge modulus, such the stresses in the torpedo pot jacket prototype σ_p depending on the stresses σ_m determined on the model are calculated with relation:

$$\sigma_p = \frac{k_f}{k_l^2}\sigma_m = K\sigma_m \quad (3)$$

The weight of the hot metal from torpedo ladle is 300 t, adding weight of the pot, including masonry, and reaching a total load of 500 t. This achieves the k_f = 500000/700 = 714 and the scale factor for stresses, k_σ = 714/82 = 11.15, which multiplies stresses values determined on the model, to obtain stresses on the prototype.

The maximum stresses in the mentioned points are σ_{10}= 86.6 MPa and σ_6 = - 109 MPa, values much lower than the allowable stresses of the material.

3. Stress State Investigation in the Box Beam by Using Combined Experimental Techniques

Box beams are manufactured of steel plates with thicknesses between 30 and 80 mm. Each beam, rested at the ends, on two bogies and is loaded in the central zone by a load of 3000 kN, transmitted from torpedo ladle through a special bolsters.

To establish maximum stressed zones, a preliminary study, using brittle coatings technique, was undertaken on the beam model made of welded sheets at scale 1: 8. The beams model, covered with brittle lake was loaded gradually, and appearance of cracks on the surface of the lake was examined.

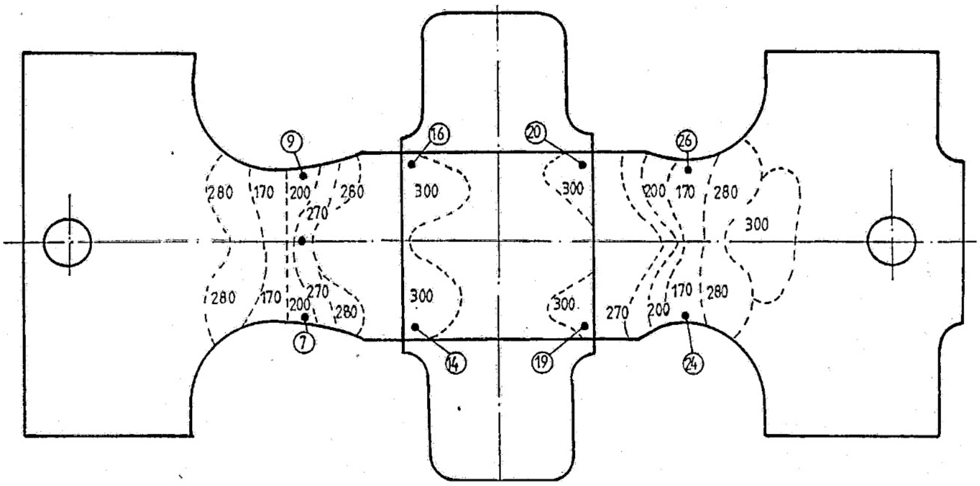

Fig. 3 Izoentatics curves

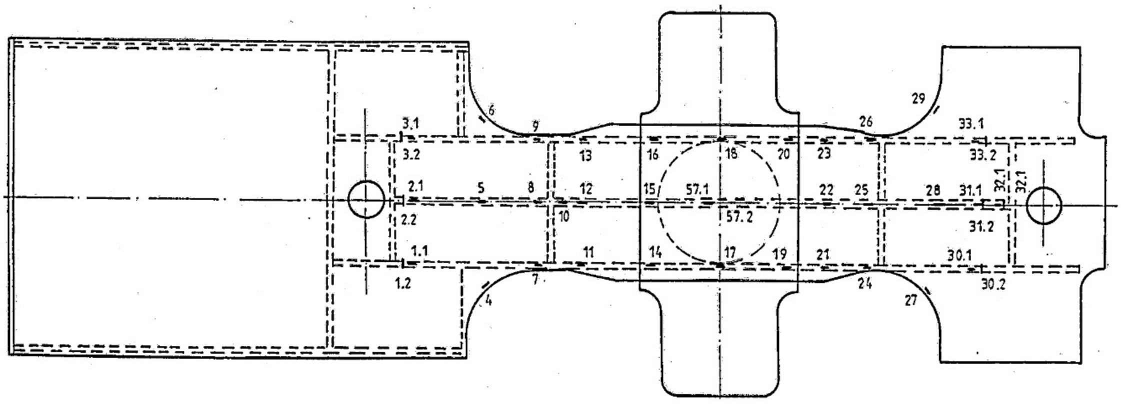

Fig. 4 Transducers placement on the prototype beam

Fig. 5 Loading of the prototype beams

The Figure 3 shows izoentatics curves determined on the lake, and values (kN), of the loads which have become visible. Results of this study, conducted on the model, were used in location of the measurement points were strain gauge

transducers will be applied, in order to investigate behaviour of caisson beam on the load. In highly stressed areas were applied, in 57 points, strain gauge transducers (on one or two directions).
The Figure 4 shows transducers placement on the prototype beam. Loading was done, in the central zone, through a special bolsters.

Table 1. Point stress values

Used techn.	Maximum stresses [MPa]				
	Measurement points				
	7	8	9	14	16
Brittle coatings	131	96.8	131	87	87
Strain gauges	140	114	131	89	89
	19	20	24	25	26
Brittle coatings	87	87	153	153	153
Strain gauges	85	88	144	147	134

Load was applied through three hydraulic presses, placed between the box beams, as shown in the Figure 5. Strains were measured for three cycles of loading – unloading between 0 and 4200 kN. Using measured strains the principal stresses were calculated by relations (2).
Maximum stresses were recorded in the points 7, 9, 24, and 26, placed at bordering columns (Fig. 4) and have not exceeded the allowable stresses of the material making up the box beams (OC 52). In the Table 1, experimental stress values are comparatively presented.

4. Stress State Investigation in the Stringers of the Bogie Prototype

Stress state in the stringers bogie was investigated using strain gauge technique on a special testing stand (Fig. 6), by loading of the bogie with a central vertical load gradually applied up to 2000kN. Strains were measured in 124 points placed on the stringers and on the windows axle of the bogie (Fig. 7 and Fig. 8). Using recording experimental data the tresses in the measurement points were calculated wits relations 2.
Experimental measurements were done on the two bogies, for three constructive variants of the stringers: a) stringers with raw windows axle at the corners; b) stringers with windows axle processed at the corners with connection of 30 mm; c) stringers with windows axle processed at the corners with connection of 50 mm. At the gradually loading of bogie, in variant a, was found that in zones situated at corners of the windows axle II and III, plastic deformations occurring at much lower loads of 2000kN.
Bogie with stringers processed in variant b was loaded up to 1850 kN without links at the bottom window and links. The calculated stresses in the point 124, for loading of 1500kN, at the bogie with links were of 208 MPa and of 379 MPa and at the unconnected window. These values are much higher than allowable stresses.
Bogie with stringers processed in variant c was subjected to four cycles of loading-unloading. In Figure 9 are show curves P = f (e) for the measuring point 124 at the four loading-unloading cycles.
As it can be seen, after the last cycle of loading-unloading, behavior of material is linear, due to cold hardening of material. Stresses calculated in the point 124, are lower by 22% and 28% compared to variant b, at the same loading. In this case, the application links to the window III was found that stresses have decreased by 26% to 31%, compared to those without links where they grew up.
All values of calculated stresseswere lower allowable stresses of the material.

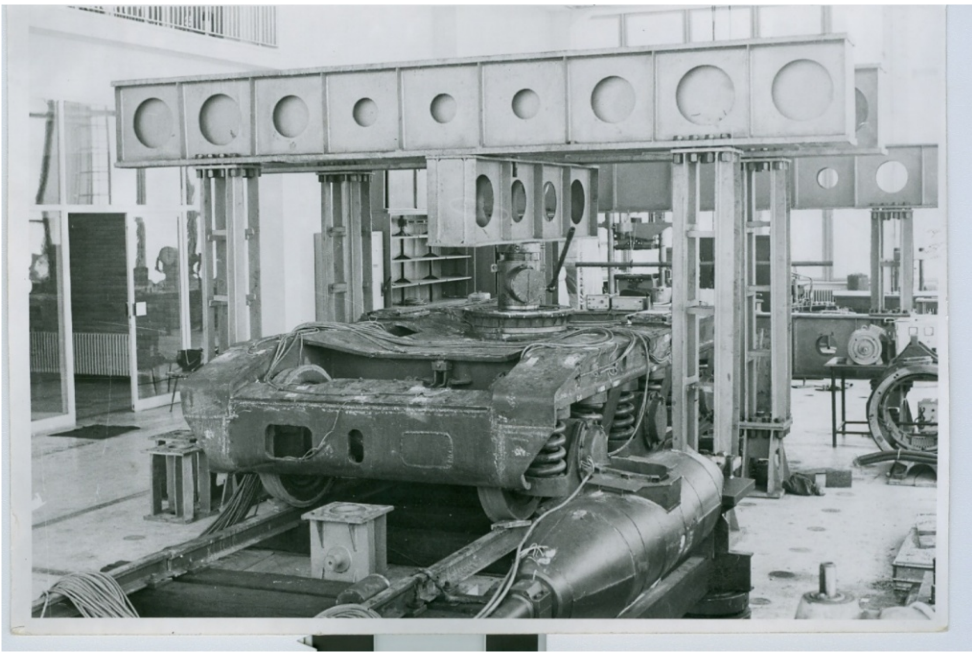

Fig. 6 The bogie prototype on the testing stand

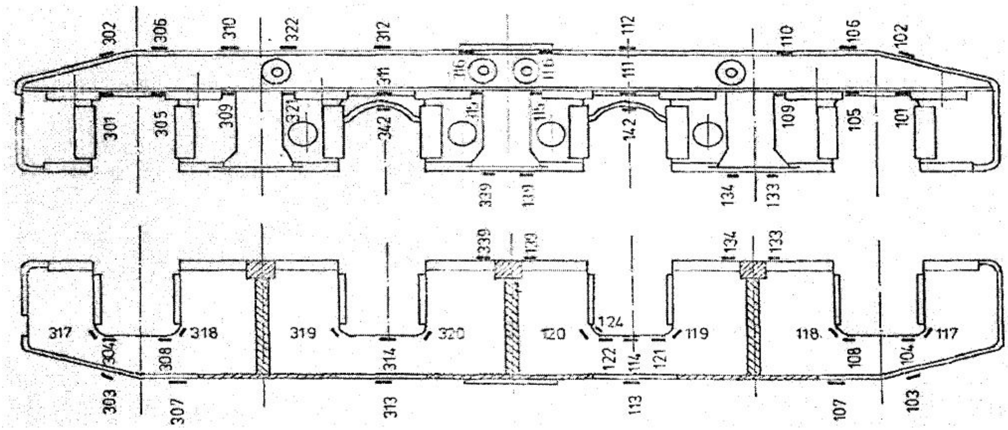

Fig. 7 Transducers placement on the bogie stringer

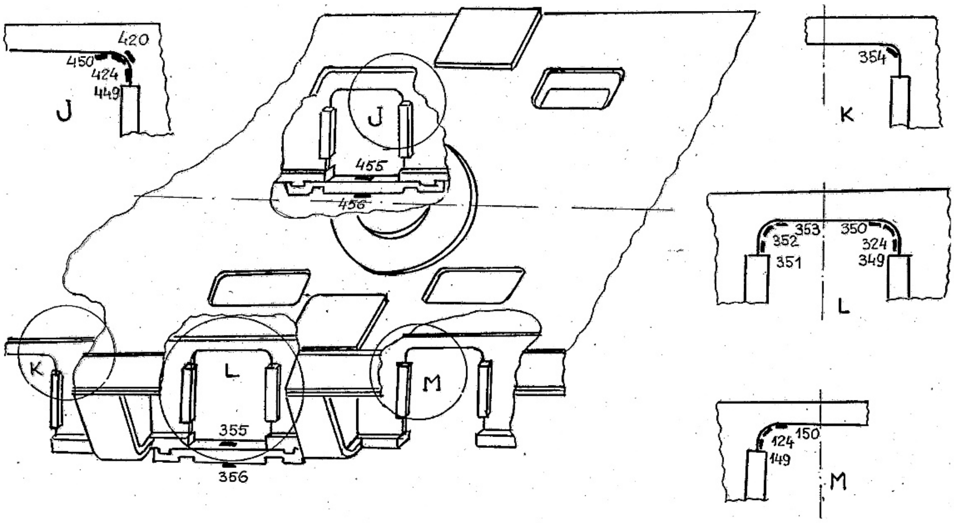

Fig. 8 Transducers placement on the windows axles

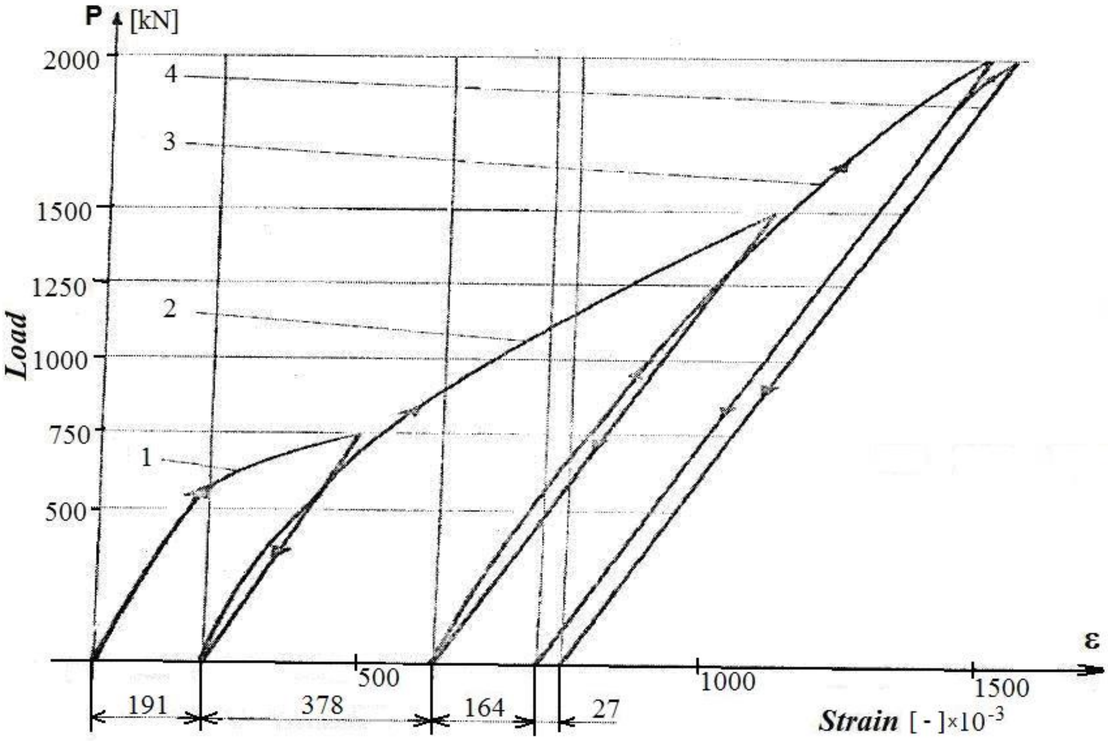

Fig. 9 Force variation versus measured strain

Fig. 10 The working point for recording and distribution of signals

5. Conclusions

Investigations carried out on the supporting structure of prototype wagon for transporting liquid iron, showed that stresses determined in the structure of the torpedo pot and in box beams, are below to allowable stresses of material.

The measurement results, carried out on the model and on the prototype of the box beam are very closed, as we can see in the Table 1.

Constructive changes proposed by the windows axle of stringers bogies led to decrease of stresses below allowable limite.

The results of this research show that the experimental analysis of the stress and strain state in the complex structures require the use of combined experimental techniques and in certain situations (in the case of large structures), research to be conducted on the structure models, performed at scale.

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