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Forecasting deflections of plates in case of perception of transient loads

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Abstract
In this paper the results of experimental research of residual deflection accumulation process in plates under the influence of repeated static loads in the mode of "creeping" and "relaxing" are presented. The main ideas of the nature of plate deformation, which make it possible to take into account the history of loading resulting deformation, and the results of modeling the process of accumulation of residual deflections in the use of short-term service loads are formulated in this document.

Introduction

While projecting hull structures with minimal weight characteristics it is necessary to achieve optimal distribution of metal between the framework and plates and the plating thickness should be chosen taking into consideration the condition of repeated perception of external loads leading it to limited plastic deformation and accumulation of deflections. For vessels in operation it is important to be able to forecast the behavior of progressing defects with the purpose of determining the terms of ship repair or determining the beginning dangerous extreme conditions when the deflections accumulate under the influence of repeated operation load. Solving these problems is related to the research of adaptability of elements of hull construction, while perceiving repeated load taking into account the influence of different factors on this process.

The problem of adaptability became evident in the seventies of the last century in the fishery shipbuilding when the professor A.G. Arkhanogorodskiy and the professor L.M. Belenkiy tried to solve the inverse problem, i.e. to determine amounts of external load by evaluating the amounts of residual deflections of plates. It turned out that amounts of load corresponding to actual deflections of plates are so great that even the grillage in the whole does not sustain them. Then it occurred to them that the deflections are caused by the load which is much less, so repeated and as a result the process of accumulation takes place.

For explaining this process a relaxation mechanism was suggested. The bottom line is that after loading of the plate in the elastic-plastic stage and subsequent unloading some residual stress field remain in the material. If this stress field change or disappear till the next loading under influence of temperature, vibration and other factors, then the residual deflection will increase. It is generally thought that this process continue, while residual stress field will be changing between loading cycles otherwise, if there is no residual stress field change, the deflections of plate will not accumulate. Some scientists followed this idea [1, 2, 3, 4].

According to other works [5, 6], the process of deflections accumulation is explained by reverse deformation of material in the zones of plastic flow. Boundary conditions of examined plates which in real operating conditions constantly change due to the appearance of embossing in related spaces, influence very strongly the deflections change. The research of the process of plates and beams deflections accumulation at different coefficients of their girt in the mode of constant repeated and static load showed that the process of accumulation stabilize at the definite quantity of loading cycles depending on the coefficient of girt.

For this reason, it was decided to carry out a complex research studying the impact of history of loading on the process of adaptivity of plates. For some simplification the tests carried out at absolutely hard girt and at developed elastic-plastic strains as the behavior of plates in extreme operating conditions of a vessel is of interest. It was very important to obtain information, whether there is summing of the residual deflection to repeated acts of loading different levels (and if so, in what way) or the total residual deflection is determined by the amount of maximum load which influenced the plating of ship's hull.

To carry out a series of experimental studies was developed program which stipulated the imposition of repeated static loads onto the plate in the definite stages. At each stage of the plates loading, the stress was applied by the packs of 50 cycles in the course of each of them the holding of the plates was carried out during 20 seconds with the same period of holding without the stress. After 50 cycles of stress the plates were unloaded and were kept without stress for the period of 24 hours. This process of loading was repeated until the adaptivity of plates came, i.e. the process of gathering the deflections is stopped. This mode of loading is called "relaxing" between the packs of permanent stress of 50 cycles the time for relaxation of the stresses. Loading mode, wherein between the packs of 50 cycles of permanent repeated static loading, the plate remained under the same loading for 24 hours, process of loading is nominally called the mode of " creeping".

In order to show influence of loading history on the resulting deflection plate, underwent the impact of repeated static loading consisting of three stages (Table 1). The loading of the first stage on the plate was $P_1 = 2$ kN, the loading of the second stage was $P_2 = 6$ kN, the loading of the third stage was $P_3 = 10$ kN.

Table 1. Variants of plates loading

Variant	Stages of loading		
Variant I	P_1	P_2	P_3
Variant II	–	P_2	P_3
Variant III	–	–	P_3

Different combination of three stages of loading allowed determining three variants of plates tests, which are presented in table 1. In each mode of loading (modes of "creeping" and "relaxing") three groups of plates were tested, the loading of which was performed according to one the variants presented in table 1. The process of accumulation of deflections w in the plate during the first variant of loading is shown on figure 1, where w_1 is the residual deflection of the plate at the first application of loading, N – number of loading cycles.

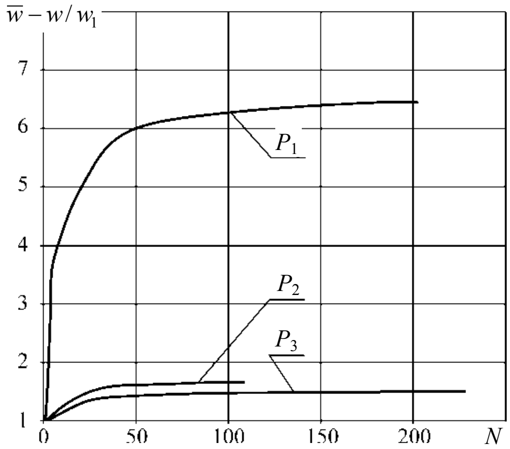

Fig. 1. Accumulation of deflections of loading in variant I

Assessed the studies performed can draw the following conclusions:

1. The accumulation happens in both modes of loading ("creeping" and "relaxing") and the level of deflections accumulation in the area of strong deformations depend on the level of external loading and it is from 2–3 thicknesses at $P_1 = 2$ kN to 5–6 thicknesses at $P_3 = 10$ kN.
2. The loading mode does not affect the resulting deformation.
3. The deflections of plates at the repeated periodic loading have the tendency to stabilizing in the range from 200 to 400 cycles.
4. The limit curve of accumulation, beyond the boundaries of which the deflections does not go out, can be achieved experimentally or by the formula [7]:

$$w_{\lim} = 2 \cdot w_{st} - 0{,}75 \cdot \frac{w_{st}^2}{w_{\mathrm{destr}}} - 0{,}25 \cdot \frac{w_{st}^7}{w_{\mathrm{destr}}^6} \qquad (1)$$

where: $w_{\lim}$ – maximum accumulated deflection, w_{st} – residual deflection of the plate at a single loading; w_{destr} – residual deflection of the plate at the moment of destruction.

5. The effect of the accumulated deflection can be removed at the reloading the plate to the intensity equal to ΔP of the level of maximum load value at which the accumulation took place.

On the basis of this research the algorithm of forecasting deflections of plates was developed which are subject to transient loading. The main ideas which allow to consider the impact of load history received deflections are as follows:

1. The whole range of external loads impact is divided into a row of levels and it is supposed that for loads within the boundaries of one level, the process of accumulation goes on equally. For each level the experimental curves of accumulation (Fig. 1) are presented in the form of rectangles, this is shown on figure 2. Where t is thickness of the plate; w is a residual deflection of the plate; P is an external load; l is a span of the plate; σ_T is a yield limit of the material; $f(\overline{P})$ is a density function of distribution of external operational load rate. The width of each rectangle is determined by the deflection growth at the corresponding cycle of loading. At the approach to the limit curve of accumulation the width of the rectangle (and the growth together with it) goes to zero.
2. A transition to a highest level is carried out in a straight line, the obliquity of which is determined according to the condition that the degree of the plate overload ΔP at which the process of deformation reaches the static curve, is similar to different levels [7]. For determining the angle of declination of the straight line of transition to a higher level, a line is drawn connecting with the point of the limit curve of accumulation of the current level with the point of the static curve corresponding to the load exceeding the current one by ΔP (dash line on figure 2). The transition from the current level will be carried out along the straight line parallel to the given line drawn from the point, corresponding to the current value of the deflection, to the horizontal line corresponding to operational load of the highest level. If the drawn line crosses the static curve at the load less than applied, then the unknown deflection will be determined by the static curve for corresponding level of operational load.
3. At the transition to a lowest level from the current one a vertical line is drawn, and in case of its crossing, the horizontal line corresponding the applied during loading of the lowest level, the deflection growth will be determined by the value corresponding to the cross point. The closer to the limit curve accumulation cross section is less and is an increase in deformation. If the vertical line crosses the limit curve of accumulation at the load, more than the applied operational load of the lowest level, then at loads of such level, the accumulation of residual deflections will not take place.

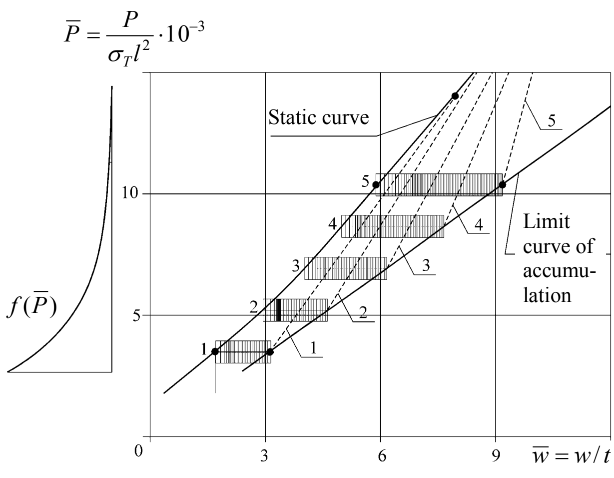

Fig. 2. Modeling the process of accumulation of residual deflection at repeated loading

Suppose that the values of external transient operational loads are distributed according to a law with density distribution $f(\overline{P})$ (Fig. 2). It is clear that not all external loads must be counted in the process of deformation of the plates but only those which will cause plastic deformations of the plate. That is why the total amount of loads causing the process of accumulation will be limited and are situated in the area of the right density distribution function side. To make the analysis simpler, the exponential law of transient loading distribution was assigned. The whole range of loads depending on their level is divided into classes. Furthermore, the quantity of load is changed, which leads to the process of accumulation from $N = 10$ to $N = 10000$. The deformation of the plate at each cycle of loading is performed in compliance with the above algorithm.

We will use the generator of random numbers for transient distribution of loads into classes according to the assigned law of external loads distributions. It is obvious that at small quantity of loads, for example, at $N = 10$, scatter of readings can be observed, because of the influence of the history of the plates loading (sequence of external loading application). To study this phenomenon, the process of calculation with small quantity of loads, was repeated many times and after that the results were averaged.

The alteration of average deflection accumulation $\overline{w}_{\max}$, depending on the quantity of model tests is shown in figure 3. It appears, that at 40–50 processes of model tests the average values of deflection stabilize. The results of these studies are described in table 2.

Analysis of the results in table 2 shows that the acquired results are physical i.e. with the increase of the quantity of loading cycles the accumulated deflection also increases and are close to the maximum value and does not exceed.

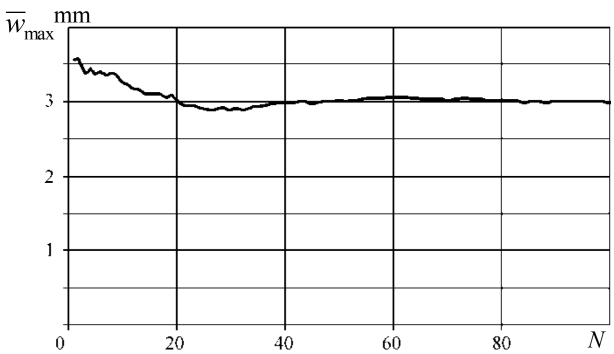

Fig. 3. Alteration of average value of accumulated plate deflection at $N = 10$ for exponential law of distribution with $\lambda = 0.07$ N^{-1}

Table 2. Results of accumulation process model test

λ, N^{-1}	N	Accumulated deflection, mm	Static deflection at loading of 3% provision $P_{3\%}$, mm	Limit curve at loading of 3% provision $P_{3\%}$, mm
0.07	10	2.99	3.55	5.53
	100	3.73		
	1000	4.66		
	10000	5.53		

Conclusions

The performed research let us draw some conclusions:

1. The hypothesis of linear summing up of deformations cannot be used for evaluating the accumulated deflection.
2. The value of maximum accumulated deflection at transient loading of plates cannot be determined on the basis of a single application of extreme loading.
3. Higher number of the quantity of loading cycles is the closer the accumulated deflection and is to the maximum under extreme load.
4. The proposed model makes it possible to forecast correctly the accumulated deflections.

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