Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 73/1/73/2 (1995)

Artikel: Strengthening of existing piers and jetties

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DOI: https://doi.org/10.5169/seals-55258

Strengthening of Existing Piers and Jetties

Renforcement des structures portuaires existantes

Verstärkung bestehender Anlegekonstruktionen

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SUMMARY

The paper presents the ways of adapting and strengthening of existing harbour structures to fulfil conditions imposed by increases in the size and draught of modern ships. Three ways of adapting are analysed, namely, through recalculation, through adequate deepening of the harbour bottom and through rehabilitation and strengthening of existing structures.

RÉSUMÉ

L'article présente les moyens de transformation et de renforcement des structures portuaires existantes, afin de les adapter à des conditions imposées par l'augmentation des dimensions et du tirant d'eau des navires modernes. Trois moyens d'adaptation à de nouvelles exigences sont présentés, soit un nouveau calcul adéquat, un approfondissement du fond marin avoisinant, et le renforcement et la reconstruction de structures existantes.

ZUSAMMENFASSUNG

Vorgestellt werden in diesem Vortrag die Methoden der Anpassung und Verstärkung der bestehenden Anlegekonstruktionen in den Häfen zur Erfüllung der neuen Bedingungen, die durch die Vergrößerung der Abmessungen und des Tiefganges der modernen Schiffe verursacht werden. Drei Methoden dieser Anpassungen und Verstärkungen wurden charakterisiert, nämlich die Durchrechnung der bestehenden Konstruktion für neue Bedingungen, die entsprechende Vertiefung der Hafensohle in der Nähe der Konstruktion und der Umbau der Konstruktion, verbunden mit entsprechender Verstärkung und Anpassung.

1. INTRODUCTION

The development of marine transport and the construction of ships in recent years indicate that ships are highly specialized and equipped with handling gear which causes high vertical loading. They have special shapes with a large longitudinal surface area, leading to high loadings on mooring devices as the result of large wind forces. The fleet of ships now in existence and being developed, particularly these vessels built to meet the requirements of certain seeways (e.g.Panamax) impose changed demands on harbour facilities, particularly on different types of berthing structures. It requires readjustment of harbour facilities to assure adequate depths, handling and mooring facilities, as well as adequate strength and stability for the significantly increased loadings.

In order to avoid any confusion caused by different terminologies, the terms wharves, quays and piers are introduced for marine structures which are used for the mooring or tying of vessels while they are loading or discharging cargo and/ or passengers. Wharves and quays are backed by warehouse areas, marshalling and storing areas, industry areas, roads, rails, etc.-areas often created by extensive fill operations. A pier is usually a rectangular wharf structure which projects out into the water while jetty is synonymous with wharf and pier [1].

In the paper the readjustment of harbour facilities, particularly piers and jetties is analysed. This analysis deals with two main factors, namely, the increase of bearing capacity of the overall structure and the increase of the depth at the berth.

When analyzing the aforementioned problem the following three methods of adapting berthing structures to the new requirements may be considered, namely:

i) The application of modern calculation methods, which take into consideration the development of theory in the field, as well as the latest results of experimental on-site and model studies.

ii) Deepening of the harbour bottom at such a distance from the berth that the stability factor of the structure and that of the underwater slope will not be changed.

iii) The reconstruction of the existing structure with the use of that structure as a structural element of a new deeper pier or jetty.

The application of the above three ways of adaptation of the existing berthing structures to the new requirements can take place only in that case in which the influence of steel corrosion and concrete deterioration is negligible.

Generally it is observed that corrosion of steel structures (e.g. steel piles, steel sheet walls, etc.) reaches the highest degree at the mean low water level while mechanical wear caused by waves, currents, ice and suspended particles of sand can cause significant reduction of the strength of the structures or stuctural elements into consideration. This means that strengthening of existing piers and jetties can be considered in such cases only if a strengthening of existing structures took place. In almost all cases, when the corrosion is observed, the existing corroded structural elements are replaced or the whole structure, having a lower strength, is introduced as a part of the new structure.

The deterioration of reinforced concrete berthing structures is caused by impact, overloading, structural movement, abrasion, lack of durability of the concrete and reinforcement, frost, chemical and electro-chemical attack. All of these causes have long-term consequential results, in that hostile environment it is allowed to penetrate the damaged structure through cracks and physical damage.

Damage of berthing structures from the marine enviroment can not in many cases be entirely avoided. It is therefore necessary, particularly in the case when the loading acting on the structure will be increased, to select design solutions so that the structure function will be fulfilled throughout its entended new lifetime despite the effects of the marine enviroment. Such results can be more easily achieved if the design of the strengthened structure is adapted to the enviromental conditions prevailing in the area, and that such solutions will be introduced which can be implemented with a high standard of engineering. In addition the design should also consider, apart from the technical strength, the durability of the structure.

It has to be metioned here that the successful design and construction of harbour structures is highly dependent on a complete knowledge of the wave "field", much more complete than the wave height and the associated period. Some of the necessary additional parameters from designer's point of view are: wave evolution over the arbitrary bottom profile, amplitude of wave oscillation at the structure wall, influence of possible erosion hole on the wave field in the vicinity of the structure and others.

2. CALCULATION METHODS

Pier and jetty strength and stability conditions can be divided into the estimation of loads, the dimensioning of the structural elements e.g. piling, coping beams, slabs, walls, etc., and the checking of the overall stability for the most unfavourable conditions of loading.

Loads on a pier or jetty originate mainly from moored ships, cargo handling equipment, transportation means, as well as merchandize stored on the structure. These loads may be analyzed with a view to their possible decrease in order to allow the structure to be used for larger vessels, which may, however, exert loads of the same magnitude, as those formerly exerted by smaller vessels.

Loads due to moored ships are mainly estimated as a function of the ship's displacement. Several national norms exist which estimate the mooring force on a bollard, or the tension and pressure on a certain length of the berth (say 1.0 m) as functions of the water depth at the structure under consideration. Both ways, however, give the values of the force or load on a bollard for a very wide range of displacements, a lower value may be 100,000 t while the upper value may be 200,000 t. This means that between the two extreme values considerable reserves may exist. Thus, it is generally recommended not to use the so-called table values, but for each particular case to calculate real force acting on a bollard as a function of the area of the ship's side, the maximum wind velocity acting perpendicular to the ship's mooring line, screening of buildings, hills, etc. of the structure under consideration and the parameters of current and waves in the harbour area. The above calculations made for a ship with a displacement of 100,000 t show that for wind speed of 20 m/s the maximum force on a single bollard may be about 650 kN in the direction perpendicular to the mooring line. This would mean that when using the Recommendations of the Committee for Waterfront Structures EAU 1990, which gives a force on a single bollard of 1000 kN, there may be a reserve of 350 kN on a single bollard with certaing arrangements of the mooring devices (perpendicular mooring ropes).

Considerable reserves also exist in crane loads, mainly because the cranes are either totally withdrawn from use (e.g. Ro-Ro ships with their own reloading ramps) or the cranes are replaced with modern ones which generally have much smaller loadings per running metre of the berthing structure. Thus if the overall stability of the structure is sufficient, the change from old cranes to modern ones may often bring a reserve in vertical loads, and consequently horizontal loads as well. In addition it must be pointed out that with a change from general purpose berth to a specialized berth, e.g. coal discharging, the number of cranes and other means of loading and transport are not only reduced but can be specified. This means that the conversion of a pier to specialized use may also allow considerable reductions in load. However, independent on the above reductions, a possible increase of the fundamental vertical bearing capacity of a berth may be considered, namely, in function of loads hitherto applied. It may be argued here that if accurately known vertical loads have been acting several years on the structure, and no significant deformation has taken place, an increase of about 30% of the permissible vertical load with respect to the maximum loads hitherto applied may be allowed.

As for the dimensioning of berthing structure elements, two main areas of interest may be touched upon, namely, the calculation of the earth pressure, if acting on the structure elements, and the bearing capacity of anchoring systems used. In the first area very simple earth pressure calculation methods have been used when designing the old structures. In the modern solutions the flexibility of the bearing elements can be taken into consideration giving considerable increases of allowed loadings. With respect to the anchoring system the possibility of reducing the anchor force applied, or increasing the allowable anchor force may be analyzed here. The first is of course connected with the reduction of all horizontal forces mentioned above together with the loads due to earth pressure if occuring. Here, only one course of action would be recommended, namely, checking the shape of the fill behind the wall. It is namely often found in berthing structures, that after many years of service, the fill has settled and has thus not only decreased in height but that also the values of the main soil parameters have increased. As for the increase of permissible anchor forces, the recalculation taking into consideration the increase of bearing capacity of compression and tension piles of a pile anchoring system may be suggested here.

The next area of berthing structure checking, when an increase in load or depth is foreseen, concerns the stability recalculation. Here it can be recommended that checks are made not of the stability of the plane running section of the structure, but of a section of the length equal to the distance between expansion joints. This allows to consider a sum of all the loads acting on the berthing structure section, which will also mean that when, for instance, possible crane loads as well as ship's mooring loads are taken into consideration, the total section of the berthing structure may absorb much larger loads then indicated by using stability checking for one running meter.

Taking into consideration all the above statements, it is possible to assume that an increase of minimum 10% of the bearing capacity of the existing berthing structure can be in any case introduced. This also means that an adequate increase of water depth is possible. Generally, if the strengthening of an existing berthing structure has to be made to increase its permissible loadings to about 15%, the recalculation of the strength, taking into consideration the above mentioned parameters, can allow to meet such requirements.

3. HARBOUR BOTTOM DEEPENING

The simplest way to reach the required depth at the pier or jetty is of course to deepen the harbour bottom either at the berthing structure or at a certain distance from it. However, regardless of the method employed it is first of all necessary to check carefully the real depth at the structure. It has namely often been pointed out that the actual depth at the berthing structure is much greater than was required even during the preliminary dredging work. This is caused mainly by natural scour in harbours and currents arising from ship's propellers. Once the actual depth is known, a full set of berthing structure recalculations must be carried out, which take the projected final loads into account. If the calculations of the existing depth allow it to be compared with the required depth, proper protection for the harbour bottom is necessary in order to ensure that this depth is maintained. This protection may take either the form of crushed stone layer, or, when it is provided at berthing structures where considerable currents are present, of concrete slabs placed on a layer of coarse sand or gravel. Using these methods a deepening of about 1.0 m with respect to the design water depth at the existing structure is possible. Of course in this case no corrections for dredging works are possible. In Fig.1 [2] an example of a scour-protection using geotextiles is given. It consists of woven geotextile (1) covered by non-woven needle punched geomembrane (2) treated mainly as a sedimentation layer (filled later by sand grains - increase of stability of the scour - protection layer), reinforcing woven geotextile (3) and balasting layer consisting of colloidal mortair units (4) (0.5 m diameter and 0.10 m height) giving an average weight of the geomembrane of about 100 kg/m^2.

The deepening of the harbour bottom at a certain distance fom the existing berthing structure should be carried out only if it can be assumed that the bearing capacity and the stability of the structure will be or is sufficiently high to take the loads projected in the new programme decided on for the structure in question. The distance depends on the berthing structure, the size of the ship, the shape of the hull, and on the mooring and fendering devices. The easiest way is to install a row of flexible dolphins at such a distance from the berth that the slope of the harbour bottom reaches the desired depth. The dolphins can be equipped with fenders of considerable diameter or thickness. This reduces the distance between the dolphin and the pier or jetty which in turn determines the length of transport bridges and other structures. The existing or required outreach of cranes is a prime consideration here. Whatever the case may be, the proposed method is recommended for berthing structures intended for the transshipment of oil, corn, and similar products, as these only require loading arms supported on special platform which may be erected between the mooring dolphins and the existing berthing structure.

An additional way of deepening of existing structures is to strengthen the bottom part of the structure allowing on necessary dredging. In Fig.2 [5] an example is given of a jetty strengthened through building of a submerged concrete retaining wall along and in between the front row piles of the jetty. After strengthening the berth pocket in front of the jetty was deepened without additional risk for the jetty foundation. It has to be metioned that for the strengthening of the bottom part of a berthing structure the high pressure jet grouting can be used.

In recent years through the introduction of bow thrusters, the harbour structures are attacked by jet velocities, causing intensive bottom scouring. This requires not only additional protection systems, e.g. using flexible revetments, but also special shape of the berthing structure together with the adjacent bottom. The main task is, however, to maintain the necessary depth without danger of bottom scouring.

4. USE OF THE EXISTING BERTHING STRUCTURE AS A STRUCTURAL ELEMENT OF A NEW DEEPER PIER OF JETTY

The deepening and strengthening of an existing berthing structure can be fairly easily carried out by replacing the old berthing structure with a new one fulfilling the new requirements concerning depth and strength. The other way is to leave the existing structure as it is and construct a new independent berth at a certain distance from the old one. The first solution is very expensive because it requires the demolition of the old structure and the construction of an entirely new one.

The prime requirement for the second solution means an adequate space in front of the existing berthing structure. This is usually coupled with a reduction in the width of the harbour basin, navigation channel, etc., which may cause considerable and unacceptable problems.

As a result of the above considerations the use of the existing pier or jetty as a structural element of a new, deeper berthing structure which will be deeper and will meet all the requirements of the authorities apper to be the best approach. Existing berthing structures may be used in various ways and for different purposes which can be listed as follows:

i) As support of a part of the new berthing structure or as a support for the main structural element of the new structure.

ii) As a support for the new berthing structure and for the reduction of the earth pressure on it.

iii) As an anchoring element for the new berthing structure.

iv) As an anchoring and earth pressure reduction structure for the new berthing structure.

The first solution (Fig.3) [3] was adopted for the reconstruction of the Ore Terminal in the Harbour of Gdańsk. In the first phase the existing structure was equipped with a new crane connected with the construction of a new crane truck; in the second phase the construction of a new coping slab supported by the old structure and new prefabricated reinforced concrete sheet wall was made. The reconstruction allowed to increase the depth at the structure from 8.0 to 11.5 m and to load it by two crane tracks, one railway track and surcharge of 30 kN/m^2.

In the second case, concerning the berthing structure of the Vistula Terminal in Gdańsk (Fig.4) [3], the existing structure consisting of anchored timber sheet wall was used to decrease the influence of earth pressure and to support partially the new coping slab. An increase of the depth of 4.0 m was reached while the loadings from cranes through constructed crane tracks were allowed.

The third solution (Fig.5) [3] was introduced for the strengthening of the Swedish Quay in the Harbour of Gdynia. The reconstruction (increase of depth, new installations, new cranes) was made by driving in the front at a distance of 1.5 m a steel sheet wall of Larssen V type, strengthened by box piles LVP. The space between the existing and new sheet pile wall was filled by compacted sand while the new upper structure was used to connect and anchor the new structure with the old one.

The last case (Fig.6) [4] concerns a structure consisting of a new inclined sheet piling wall, driven in front of the existing structure and attached to the remainder of the old structure by prestressed anchors. The bottom at the previous seabed level is secured by an underwater concrete plug. The strengthening of the existing berthing structure allows on the increase of the depth from -7.0 m to -12.5 m. The front wall is a combined HZ-steel wall in which the Z-sheets are driven from the level -3.5 m to -14.5 m.

The presented cases clearly indicate the possibilities of strengthening of the existing berthing structures to meet the requirements arising from the changes occuring in recent years in the marine transport.

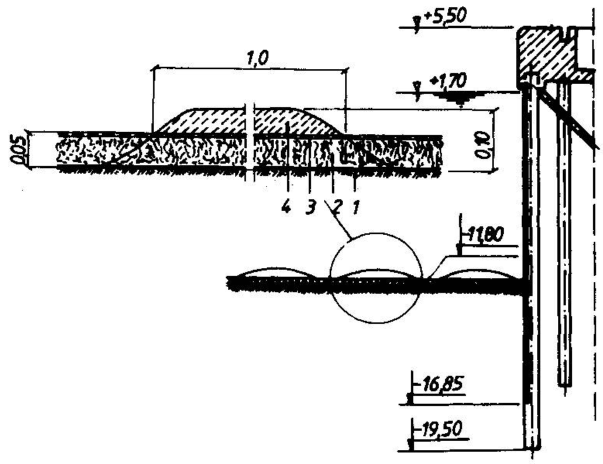

Fig.1 Bottom protection using geotextiles [2]: 1-woven textile, 2-geomembrane with sand, 3-reinforcing geotextile, 4-mortair

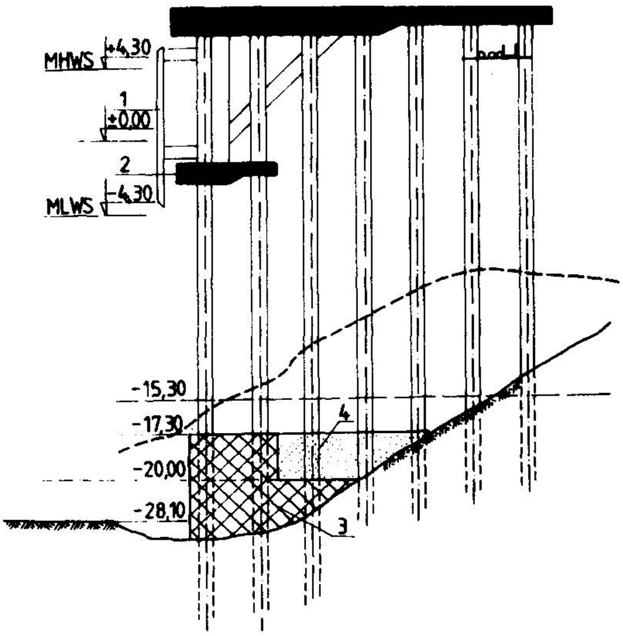

Fig.2 Strengtheing of an existing jetty through a submerged retaining wall [5] 1-main fender, 2-concrete fender tray, 3-concrete retaining wall, 4-soil refill

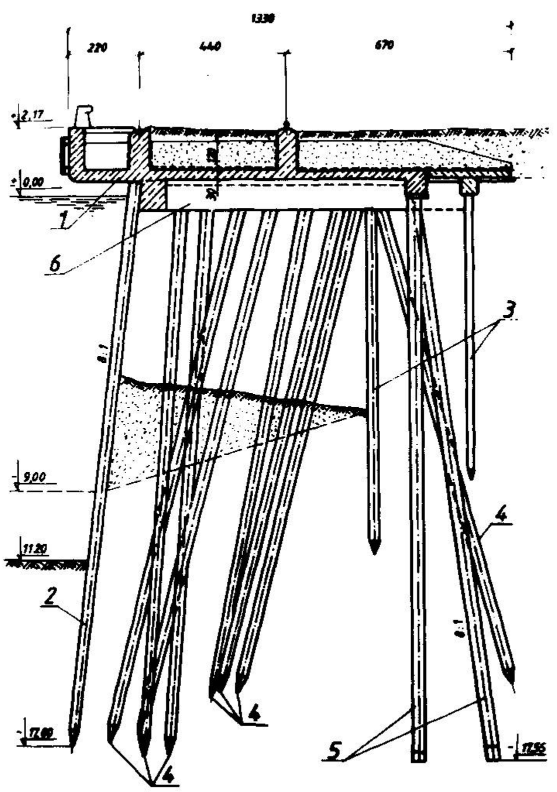

Fig.3 Reconstruction of the Ore Terminal berthing structure in Gdańsk [3]: 1-new reinforced concrete slab, 2-concrete sheet wall, 3-existing timber sheet wall, 4-existing timber piles, 5-concrete piles, 6-existing concrete slab with reduced thickness

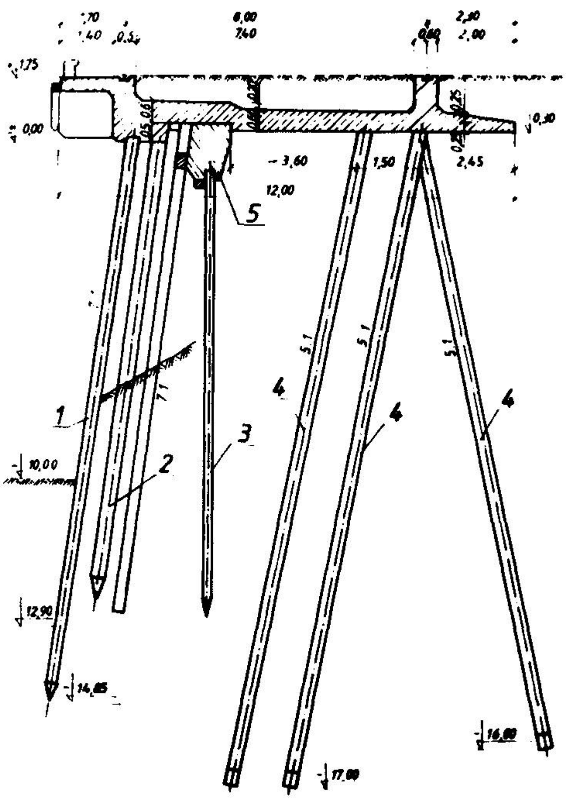

Fig.4 Strengthening of the berthing structure of the Vistula Terminal in Gdańsk [3]: 1-concrete sheet wall, 2-existing timber piles, 3-existing timber sheet wall, 4-concrete piles, 5-existing concrete coping beam

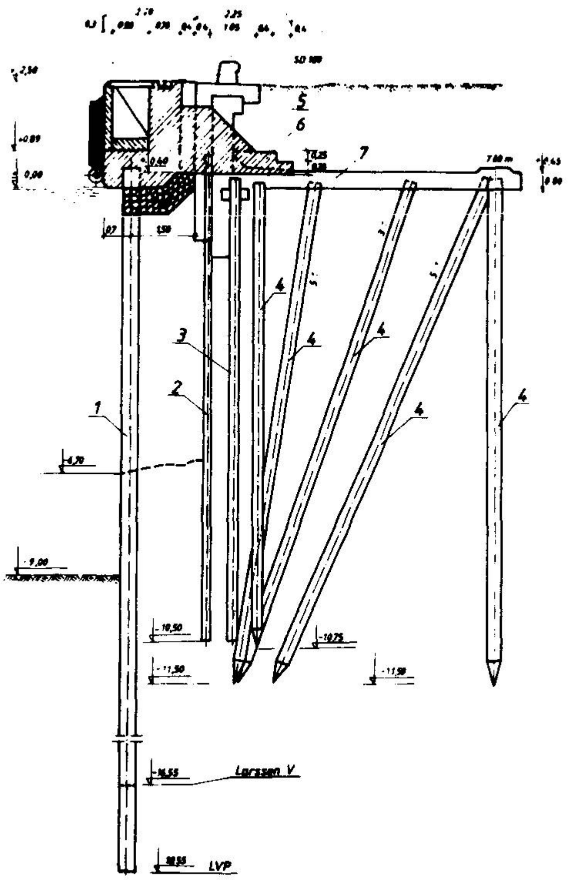

Fig.5 Strengthening of the Swedish Quay in Gdynia [3]: 1-steel sheet wall Larssen V strengthende with box type piles LVP, 2-existing timber sheet wall, 3-steel sheet wall, 4-timber piles, 5-longitudinal anchoring beam, 6-transverse anchoring beams, 7-existing cover plate

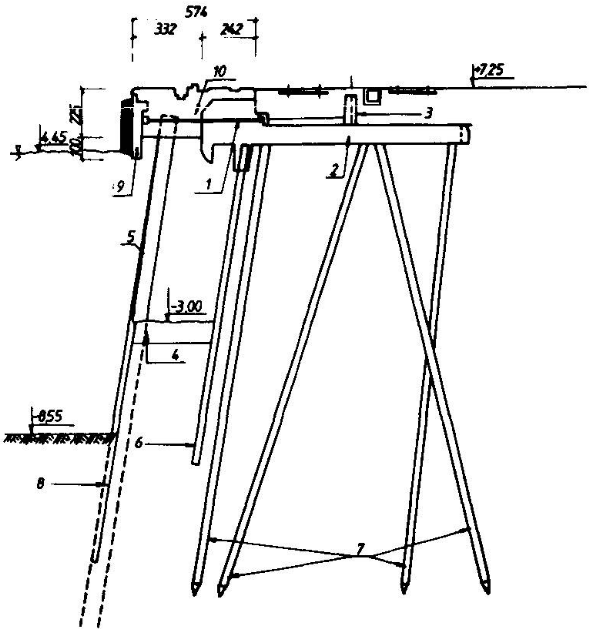

Fig.6 Cross-section of the strengthened berthing structure [4]: 1-prestressed anchor, 2-existing cover plate, 3-new crane-rail beam, 4-concrete, 5-H-piles, 6-existing BZ-sheet piling, 7-existing concrete piles, 8-Z-sheets, 9-prefabricated element, 10-new head beam.

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