stability.” The change may occur at very small angles if the ship is crank and her sides are low in the water. It may not and sometimes does not occur, on the other hand, until the ship is lying on her beam ends.

If a curve is plotted out showing these positions and indicating also how *d* first increases and then decreases as the ship is inclined more and more from the upright, the curve is known as the curve of stability. A “stiff

ship” is one which

opposes great resist­

ance to inclination

from the upright

when under sail or

acted upon by ex­

ternal forces. A

“ crank ship” is one

very easily inclined,

the sea being sup­

posed to be smooth

and still. A “steady

ship ” is one which when exposed to the action of waves keeps nearly upright. Crank ships are usually the steadiest ships. Changes in the height of the point cf intersection M (fig. 4) above the centre of gravity indicate corresponding changes in the stiffness of a ship. Speaking generally, the stiffness of the ship may be considered to vary with the height of M above G. The line BM does not cut GM in the same point at considerable inclinations as it does at a very small inclination. The point of intersection at the smallest conceivable inclination receives a definite name. It is known as the metacentre, and the distance GM is in this condition called the metacentric height. See Hydromechanics.

The following table contains particulars of the metacentric heights of different kinds of vessels of war, and the corresponding time of an oscillation in still water :—

|  |  |  |
| --- | --- | --- |
| Names of Ships. | Metacentric  Height. | Period of a Double Roll. |
| H.M.S. “Sultan,” | Feet.  2∙5  2∙8  3∙7  14·0  7·65 | Seconds.  8∙9  8∙0  6·76  2∙7  10·7 |
| H.M.S. “Inconstant,” |
| H.M.S. “Devastation,” |
| American monitor (shallow draft),  “Inflexible,” when rolled in still water in Suda Bay, |

Generally speaking, decrease in metacentric height is accompanied by a lengthening of the period of an oscillation. The ship swings more slowly as she loses stiffness.

There is no sensible difference in the time occupied by a ship in a swing or roll from side to side, whether she rolls through only three or four degrees on either side of the upright or twelve or fifteen degrees. For larger angles there would be small differences.

The tables which have been given show some remarkable changes in the stability conditions in ships of war within recent years. Sailing ships were formerly made with so little deviation from existing types that it was not found to be necessary to ascertain their exact measure of stability or to lay down rules for regulating it. The position of the centre of gravity was modified by ballast, and as much as nine or ten per cent. of the displacement was allowed for this. Heavy rolling and great uneasiness of ship from excessive stability had often to be endured. In other cases crank­ness or inability to carry sail had to be accepted. When armoured ships were first introduced they had about the same metacentric height (6 feet) as is to be found in the earlier sailing frigates. The “Normandie” in the French navy and the “ Prince Consort” in the English navy had from 6 to 7 feet, and they were exceed­ingly uneasy and deep-rolling ships. It was soon discovered that a reduction in metacentric height would cure this evil. The later ships in both navies were accordingly designed to have a metacentric height of about 3 feet. The “Magenta” had 31/4 feet and the " Hercules ” 3 feet. This change altered the period during which the ship made a double oscillation, *i.e.,* from star­board back to starboard, to 14 to 16 seconds instead of 10 to 11 seconds, as it had been in the “Normandie” and “Prince Con­sort.” The effect on the behaviour of the ship in a seaway was most remarkable. These ships with small metacentric height might be put into the trough of a sea, and as the waves crossed them they steadily rose and fell, hardly inclining their masts. The effect on gunnery practice was also valuable, but there is always a peril attending steadiness obtained by such means : vessels having small metacentric height require careful handling under sail or they may be overset and lost. There is another defect in this system, viz., that wounds in action will cause the ship to incline sooner and more considerably, and they become more dangerous than they would be in a stiffer ship. Bilge-keels and water- chambers are now employed in the English navy, together with, and as opposing influences to, much greater metacentric height.

These devices were introduced into the “Inflexible” in order to counteract the influence of a metacentric height of 8 feet which was designedly given to her. They have proved very effective, but there is another feature in this vessel which has tended to prevent uneasiness and heavy rolling. The time of an oscillation, or quickness of rolling, depends not only upon the metacentric height but upon the moment of inertia about a longitudinal axis. The time of an oscillation from starboard to starboard may be written thus :—

2T = 1∙1√K2∕m,

where T is the ship’s period in seconds for a single roll, *m* is the metacentric height, or height of metacentre above the centre of gravity in feet, and K is the radius of gyration in feet. The moment of inertia is increased by widening the ship, putting heavy armour on her sides, and placing the turrets and guns out towards the sides of the ship. It was seen that these features in the “Inflexible,” which were elements in her design, would favour her and tend to counteract the great metacentric height. The event has shown that, while a metacentric height of 6 feet in the “Normandie” gave 10 seconds to 11 seconds period, 8 feet in the “ Inflexible” only gives 11 seconds as a period, corresponding with a radius of gyration of 28 feet. The feeling expressed that “in order to provide against the impossible contingency of the loss of stability by complete waterlogging of the ends we had made an intolerable ship” was not justified. The ship is now so stiff that when the ends are waterlogged the running in and out of all her guns on one side only inclines her 2 1/2 degrees, while in the " Monarch ” when intact and light the same operation inclines the ship 5 degrees.

The resistance offered by the water to the rolling of the ship consists of three parts :—(1) that due to the rubbing of the water against the bottom of the ship as she rolls ; (2) that due to the flat surfaces which are carried through the water, such as outside keels and deadwood ; (3) the creation of waves by the rolling ship to replace those which move away from the ship. The creation of these surface waves expends energy and checks the motion of the ship which makes the creative effort.

Mr White, giving briefly the results of some of the experiments of Mr Fronde made for the Admiralty, says :—

“ Experiments have been made by Mr Froude to show how rapidly the rate of extinction may be increased by deepening bilge- keels. A model of the 'Devastation' was used for this purpose, and fitted with bilge-keels, which, on the full-sized ships, would represent the various depths given in the following table. The model was one thirty-sixth of the full size of the ship, and was weighted so as to float at the proper water-line, to have its centre of gravity in the same relative position as that of the ship, and to oscillate in a period proportional to the period of the ship. In smooth water it was heeled to an angle of 8 1/2 degrees, and was then set free, and allowed to oscillate until it came practically to rest, the number of oscillations and their period being observed. The following results were obtained :—

|  |  |  |
| --- | --- | --- |
| Model fitted with | Number of Double Rolls before Model was practically at rest. | Period of Double Roll. |
| No bilge-pieces | 311/2 | Seconds.  1∙77 |
| A single 21-inch bilge-keel on each side | 121/2 | 1∙9 |
| ,, 36-inch ,, ,, | 8 | 1∙9 |
| Two 36-inch ,, ,, | 53/4 | 1∙92 |
| A single 72-inch ,, ,, | 4 | 1∙99 |

“ Not content with obtaining the aggregate value of the resistances for ships, Mr Froude has separated them into their component parts, assigning values to frictional and keel resistances as well as to surface disturbance. In doing so, he has been led to the con­clusion that surface disturbance is by far the most important part of the resistance offered to rolling, as the following figures given by him for a few ships will show :—

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Ships. | Frictional. | Keel, Bilge-keel, and Deadwood. | Total  Resistance. | Surface  Disturbance. |
| Sultan | 354 | 5,036 | 20,000 | 14,610 |
| Inconstant | 140 | 4,060 | 21,500 | 17,300 |
| Volage | 96 | 2,944 | 14,100 | 11,060 |
| Greyhound | 120 | 700 | 4,700 | 3,880 |

“ Frictional and bilge-keel resistances in this table have been obtained by calculation from the drawings of the ship, Mr Froude making use of data as to coefficients for friction and for head resistance which he had previously obtained by independent experiments, and which may therefore be regarded as leading to thoroughly trustworthy results. It will be noticed that in no case does the sum of the frictional and keel resistances much exceed