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Analysis on a Cast-Iron Pipe Applied to Protection of Underwater Cable

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Abstract: In this study, a protection-pipe system is developed for the protection of undersea electricity power cable laid along shoreline with medium deep water. The protection-pipes are made from ductile cast-iron alloys while the dimensions are designed corresponding to the diameter of balk electricity power cables. In order to know if the protection-pipe is strong enough to prevent the power cable from damages caused unnaturally, such as berthing anchoring from large size ships or towing operation from fishing boats, both analytical and experimental studies were carried out. Presented in this paper is an analytical study based on the material mechanics. A finite element analytical method was applied and the deformed shapes on the protection-pipe were studied. Along with the deformation, the corresponding stresses were also presented. In order to know the response of the protection-pipe subjected to an impact loading exerting on various parts of the pipe, several analysis for various loadings and boundary conditions were performed. It was found from the results of the analysis that the proposed protection-pipes are able to meet the requirements of TPC set for the electricity power cable laid under seawater.

Keywords: Ductile Cast Iron, Structural Safety, Protection Pipe, Undersea Pipeline, Finite Element Analysis

1. Introduction

Safety and accountability for underwater pipelines and cables being able to operate appropriately is always an important issue. Environmental challenges including chemical, mechanical and biological elements are usually inevitable for structures under seawater. In order to reduce the environmental influences and lengthen the service life of the structures, many types of protection devices for the underwater cable systems have been developed.

The protection pipe is designed to protect the electricity power cables across the strait through the sea bottom, especially for the parts that are not fully buried under the sea soil but laid on the seabed or suspending exposed in water. The risk for the electricity power cable exposed in seawater includes the environmental hazards and threatening of human operation in ocean. Environmental hazards could be ranged from the regular ones such as the water pressure, possible corrosion, erosion and abrasion from sand and debris action under sea to the major hazards like huge storms, earthquakes and tsunamis et al. [1, 2, 3, 4] Most cable systems are able to resist the regular threatening but for the major hazards [5, 6], special design based on the degree of the natural hazard must be applied. As for the threatening of human being activities such as the possible damage from ship anchoring or fishing operation, especially an impact loading or dragging exerting on the cables, it will be very dangerous and may cause serious damages. Therefore, a protection pipe will be necessary such that the cable can be covered around to avoid direct exposing to harmful objects such as plunging anchors from ship berthing.

Therefore, in this study, a protection-pipe system is developed for the protection of undersea power cable laid along shoreline with medium deep water. Many protection system for the underwater cables are developed such as the excavation of ditches under seabed for the cables laid, the application of concrete mats on the laying site of the cables and the more traditional application by using protection rocks. The idea to use a protection pipe of which no matter what is made is not rare. The application of half-pipes made of concrete as a protection-cover for cables is a common practice. A cast-iron protection pipe is a more expensive but safer practice. The protection-pipes are made from ductile cast-iron alloys while the dimensions are designed corresponding to the diameter of balk electricity power cables. The water depth of the area with cable laid is ranged from several meters to a hundred meters, where berthing anchoring from commercial ships and towing operation from fishing boats are constantly found. Therefore, to make sure that the protection-pipe can work appropriately against the loadings mainly from the operation such as berthing anchoring from large size ships or towing operation from fishing boats as mentioned above, both analytical analysis and experimental tests were carried out. It was found from the results of the analysis that the protection-pipes are able to meet the requirements of TPC set for the cable layout under seawater.

2. Protection Covering Pipe

2.1. Ductile Cast Iron Material

Cast iron is a group of iron-carbon alloys with a carbon content greater than 2%. For most of these cast irons (grey irons), the graphite exists in the form of flakes, which are normally surrounded by ferrite or pearlite matrix. A cast iron material is usually treated as a material with brittle mechanical properties. A typical fracture behavior from von Mises yield function is shown in Fig. 1 [7], where the material to be studied is a grey cast iron containing 3.3% carbon and other gradients of silicon, manganese and chromium with pearlite matrix. It shows that the yield stress in tension is only one third of that in compression. The low yield strength is believed to be caused by local cracks of microscopic size in the pearlite matrix at the graphite flakes due to the high stress concentrations.

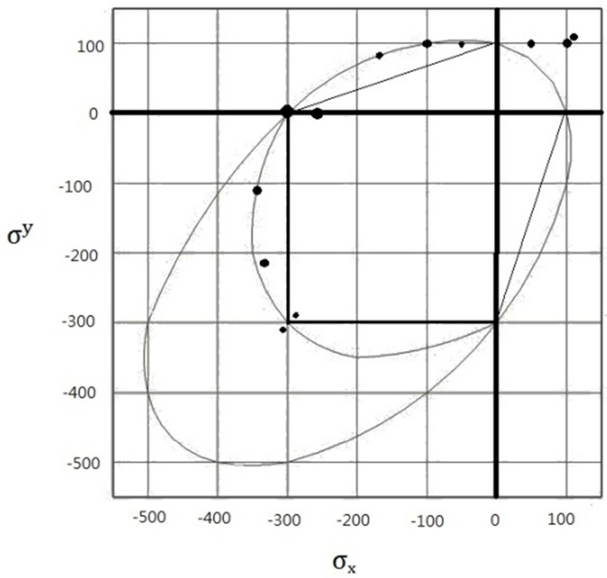

Fig. 1. *A typical fracture behavior of cast iron redrawn after (von Mises yield function) [7].*

In 1943, at the International Nickel Company Research Laboratory, Keith Dwight Millis put some addition of magnesium (as a copper-magnesium alloy) to cast iron and then the solidified castings contained not flakes, but nearly perfect spheres of graphite. Because the spheres of graphite don't act as stress raisers but as crack arresters, the cast iron then has its ductility. That was the opening of the broad way for the popular application of the ductile cast iron. In many ways the ductile cast iron has a behavior very similar to steels.

A typical microstructure shown in schematic drawing is presented in Fig. 2 [8] and a more detailed picture from SEM in Fig. 3 [9].

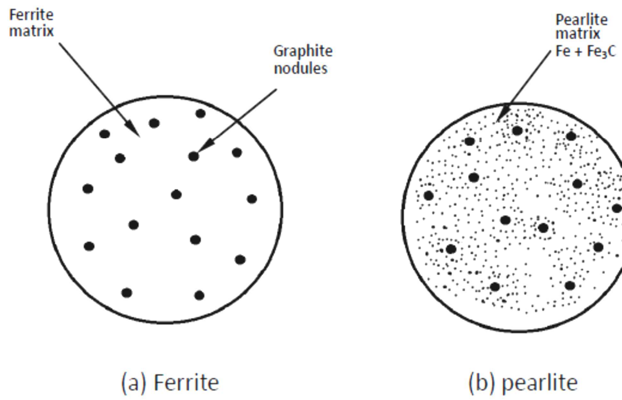

Fig. 2. *A schematic view of microstructures for the ductile cast iron redrawn after [8].*

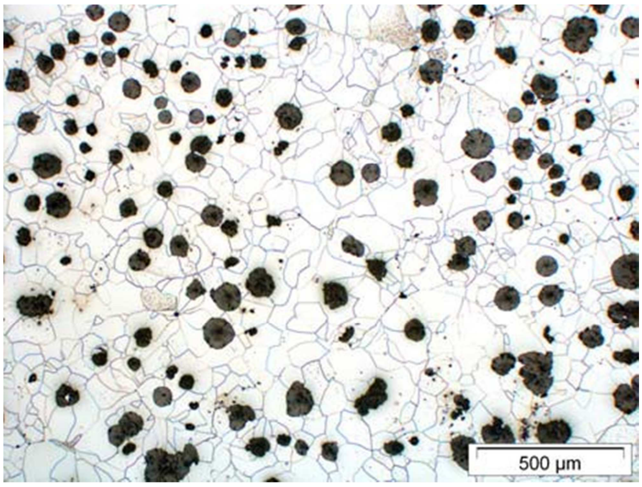

Fig. 3. *The microstructures of the purely ferritic cast iron [9].*

This new form of cast iron immediately found uses where malleable iron, forgings, cast steel or steel fabrications would have been used.

2.2. Composition of the Protection Covering Pipe

Basically, the material used for the proposed protection-pipe is composed of ductile cast iron of high strength. According to Taiwan's standard CNS2869 FCD500 for the material properties, the required basic mechanical properties include the minimum tensile strength, yielding strength, elongation rate, hardness and the rate of sphericity as shown in Table 1 [10]. Compared to Fig. 1 for the traditional or grey cast iron, the tensile strength is as high as 500 Mpa, which is much greater than the value of 100 Mpa.

Table 1. *The mechanical properties of the material for protection pipe [10].*

Tensile strength Kgf/mm^2(N/mm^2)	≥ 51 (500)
Yielding strength Kgf/mm^2(N/mm^2)	≥ 33 (320)
Elongation rate %	≥7
Hardness HB	150~230
Sphericity rate %	≥ 80

2.3. Size and Dimension of the Protection Covering Pipe

A typical undersea (submarine) cable contains many small groups of wires or cables, as shown in Fig. 4, which may have various purposes. Some of the undersea cables may have protective armors around the surface of the cable while the others usually, don't have any protection because depending on the environmental conditions of the cable laid, various protection methods may be applied. A typical proposed cast iron protection-pipe is shown in Fig. 5, where it is noticed that only half pipe is shown. It is because that during the laying work of the pipe, the protection-pipe will cover up the power cable from two half-pipe into a whole-pipe in a piece- by- piece and sec-by-sec scheme.

Fig. 4. *Various cables for different application [google.com].*

A detailed drawing of the protection pipe is shown in Fig. 6, where the detail of size is shown. The tolerance for thickness difference from each other along the pipe is limited to ±1.0mm while for the other parts, the difference-tolerance is ±3.0mm.

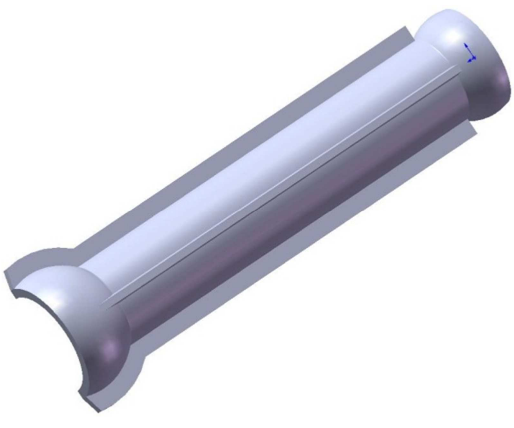

Fig. 5. *The tpical shape in half of protection-pipe.*

3. Numerical Simulation

3.1. Application of Impact Loadings

The most likely impact loading exerting on the protection covering-pipe laid near shoreline seawater will be the berthing anchors from either a fishing boat under fishing operation or a temporarily stationed ship, which may park offshore temporary on a waiting-line for the entrance to a harbor nearby. Therefore, the impact loading induced from ship berthing was considered and modeled for the behavior of protection covering-pipe subjected to such loadings. During the analysis, assumptions were made for the simulation of the impact loadings for an anchor plunging under water such as: (1) the buoyancy of the anchor was considered as static; (2) the covering-pipe was totally exposed; (3) the sea-bed was assumed to be hard without any damping. For real practice, anchors are laid into water through chains within certain speeds.

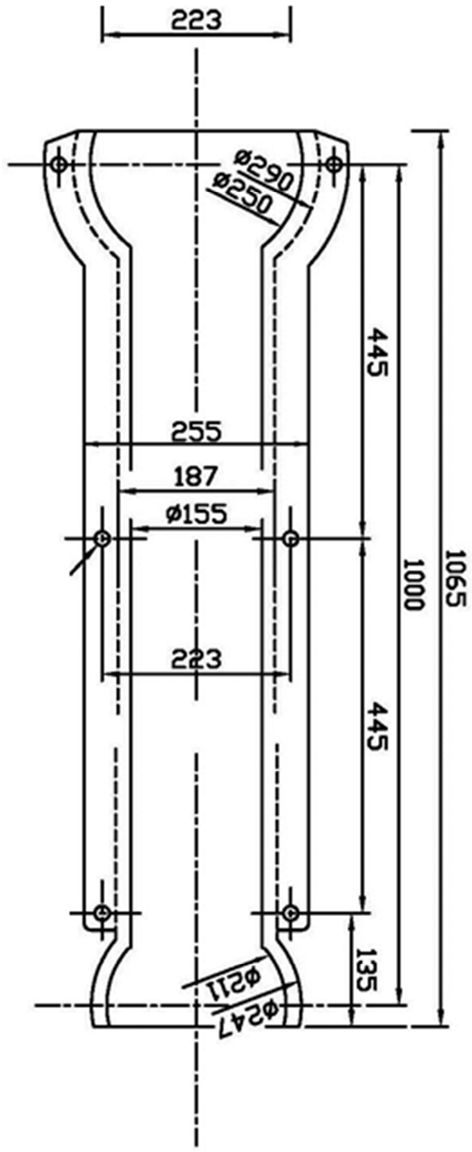

Fig. 6. *The drawing of the protection pipe details*

However, the simulation in this study will be more near the extreme cases. From the fore-mentioned assumptions, the impact force F_I induced from a three tons of anchor of Baldt-type was estimated as:

$$\begin{aligned} MV &= F_I t \\ \Rightarrow F_I &= MV / t \end{aligned} \tag{1}$$

It is noticed that the impact force will be varied according to the duration of the exertion. The speed of the anchor is assumed to be 250 m/min. the maximum anchoring speed according to the regulation of IACS (International Association of Classification Society). Then the impact loading can be determined with respect to the plunging duration.

3.2. Simulation for the Pipe

For the numerical analysis, several conditions that the anchor impacts on various parts of the covering pipe were taken into consideration. The first case is the simulation for half-pipe subjected to impacting from plunging anchor, in which the flange-collar, the reinforcing rib and non-reinforcing web of the pipe was alternately subjected to impacts and deformation of the pipe was examined. For the second case, a whole covering pipe was subjected to impact loadings, which was exerting on the various part of the pipe as indicated in case one. Shown in Fig. 7 is the half pipe under numerical analysis which was descretized with grid meshes in the finite element analysis.

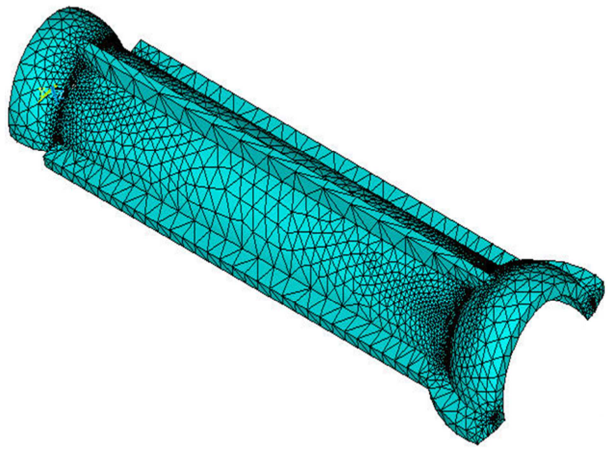

Fig. 7. *The gid mesh for the half pipe under analysis.*

3.3. Half Pipe Subjected to Impact on Reinforcing Rib

When the whole covering pipe was composed by two half parts of the pipe and the sea bed was assumed to be rigid, a symmetrical response was assumed for the covering pipe and then the half-pipe analysis was performed. As shown in Fig. 8 is the deformation of the half-pipe subjected to impact loading on the reinforcing rib. The rib was deformed away from the original position but the body of the pipe seemed not damaged very seriously. The maximum deformation of the reinforcement rib is 0.096215 mm according to the analysis.

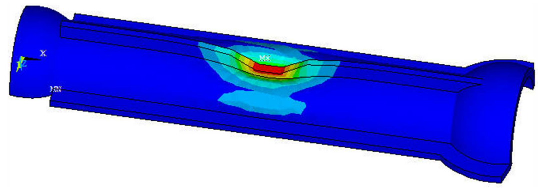

Fig. 8. *Deformation of the pipe subjected to impact on the reinforcing rib.*

3.4. Half Pipe Subjected to Impact on the Web

Shown in Fig. 9 is the deformation of the half-pipe subjected to impact loading on the web. Significant damage could be observed at the impact loading exerting part even though the expansion of the damage is not large. The maximum deformation of the web is 0.087341 mm according to the analysis.

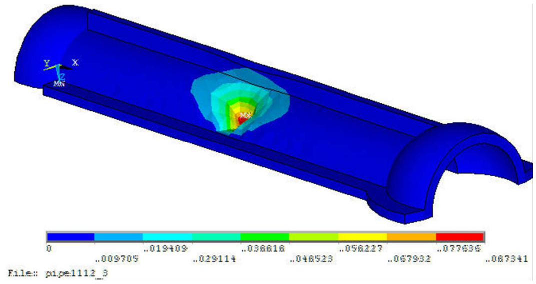

Fig. 9. *Deformation of the pipe subjected to impact on the web.*

3.5. Half Pipe Subjected to Impact on the Connection Collar

In the impact dynamic analysis the damage is most serious for the connecting collar of the protection pipe was hit by the loading. As was shown in Fig. 10, where clear concave deformation can be observed on the collar of connection. The maximum deformation of the connecting collar is 0.12149 mm according to the analysis. It is much larger than the deformation of the other parts of the protection pipe subjected to a similar impact loading. Therefore, it is considered as the weakest part of the protection pipes laid-out on the seabed. Of course, the collar part of the pipe will be connected to the collar of the other pipe in a manner of layer by layer. In that way, the thickness of the collar is doubled and the strength of the connecting collar is expected to be more enhanced.

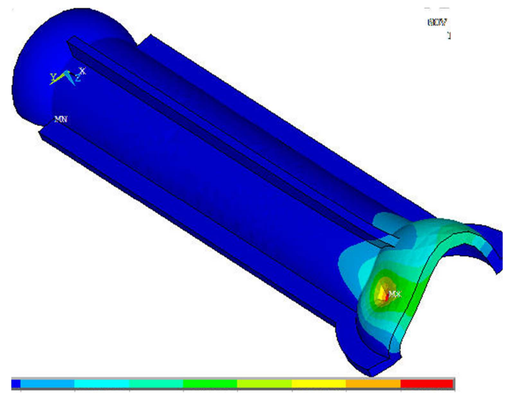

Fig. 10. *Deformation of the pipe subjected to impact on the connection collar.*

3.6. Whole Pipe Subjected to Impact on the Reinforcing Rib

To understand the behavior of the pipe subjected impact loading when the pipe was freely laid on the seabed, an additional analysis for the whole pipe was carried out. The whole protection covering-pipe composed of two half parts of the pipe is also subjected to an impact loading on the reinforced rib along the body. As shown in Fig. 11 is the deformation of the half-pipe subjected to impact loading on the reinforcing rib. The rib was deformed and bended down from the original position and affected the body of the pipe in some degree of depth. The maximum deformation of the reinforcement rib is 0.361 mm according to the analysis. It is much more serious compared to the analysis of half-pipe case.

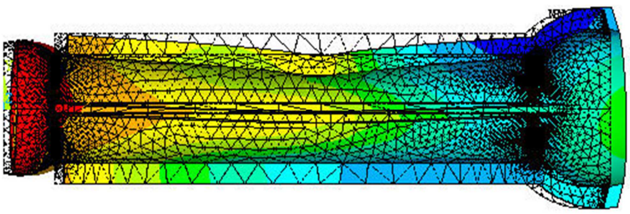

Fig. 11. *Deformation of a full pipe subjected to impact on the reinforcing rib.*

3.7. Whole Pipe Subjected to Impact on the Web

Shown in Fig. 12 is the deformation of the whole-pipe subjected to an impact loading on the web. Significant damage could be observed at the impact loading exerting part even though the expansion of the damage is not large. The maximum deformation of the web is 1.85 mm according to the analysis, that is about five times deformation compared to the case, where the damage is on the reinforced rib. It states that pipes reinforced with the rib reinforcement along the body may have minor deformation as long as the impact is on the rib instead the body itself. This is an additional benefit from the rib reinforcement in addition to the enhancement of the flexural rigidity to the pipes.

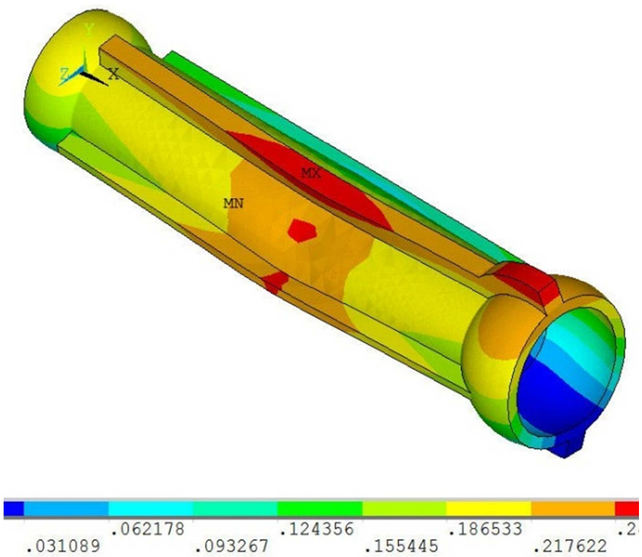

Fig. 12. *Deformation of the pipe subjected to impact on the web.*

4. Discussion and Conclusion

In this paper, a covering pipe to protect the underwater electricity power cable made of ductile cast-iron was studied for its performance when subjected to impact loadings. The study includes basically, a numerical analysis for the half-pipe and a whole-pipe model. It appears to be that the results from the analytical study are conservative. The analytical results show that a maximum deformation could reach by as high as 1.85 mm when the web of pipe was subjected to an impact loading. Even for the case when the reinforced rib of the pipe was subjected to impact loading, the deformation of pipe is still as large as 96×10^{-3} mm.

The most critical situation for the half-pipe analysis appears at the case when the connecting collar (connecting head) is subjected to the impacting loading. The maximum deformation of the connecting collar is 0.12149 mm according to the analysis. It is much larger than the deformation of the other parts of the protection pipe subjected to a similar impact loading.

The analytical results from the whole-pipe analysis are much more critical. It seems to be that the deformation induced from the impact loading is more significant to the pipe. It is understandable that for the half-pipe analysis, the boundary conditions are set to be more rigid to avoid a rigid body motion during the analysis. However, for the whole-pipe analysis, the restraints to the analytical model were not reduced while the pipe has a larger cross section.

As for the stress analysis, the results from testing data are smaller than the yielding strength of the material, which is 320 MPa while the maximum deformation stress during the test is 137.7 MPa.

Therefore, according to the results of analytical model study, it is concluded that the proposed cast-iron type protection pipe for the undersea electricity power cable could work effectively in terms of resistance to an impact loading from berthing anchoring threatening. It is also concluded that results from numerical analysis could be varied depending on the variation of parameters used for analysis.

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