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INTERNAL DAMAGE TO WIRE ROPES ON CRANE : CASE STUDIES OF FRACTURE ACCIDENTS AND COUNTERMEASURES FOR PREVENTION

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ABSTRACT

Recently in Japan, considerable number of crane accidents due to the fracture of IWRC wire ropes occurred. From the results of the precise analysis of such crane accidents, it was predicted that IWRC wire ropes were prone to internal damage. Therefore, in this study S-bending fatigue tests were conducted on two kinds of IWRC wire rope under a wide range of testing conditions to certify the prediction. The results showed that it was correct. This means that the present situation would be serious, because wire rope inspections are commonly completed by visual observation of external features, which would not reveal internal damage.

To improve such situation, several countermeasures against internal damage inherent in the IWRC wire rope were examined, and two methods were eventually selected as the most practical ones.

KEYWORDS

Wire rope, Crane, Fracture accident, Internal damage, Bending fatigue, Damage inspection.

1. INTRODUCTION

Recently in Japan, IWRC (Independent Wire Rope Core) wire ropes are extensively used for cranes, especially for mobile cranes. Under such situation considerable number of serious crane accidents due to the fracture of wire ropes occurred during the last decade ［1］. However, the proper practical countermeasures had not been proposed because the essential cause of this kind of accident has not been clarified,.

Therefore, in this study, accident cases which resulted in casualties (death) were reviewed and the failure properties of IWRC wire ropes were investigated first. Then, to certify the prediction obtained by the first investigation that the wire ropes of this kind are prone to internal damage, a series of S-bending fatigue experiments were conducted on two kinds of IWRC wire ropes under a wide range of conditions, and the problem of the present situation relating to the safety aspects of inspection was pointed out ［2］. Finally, several countermeasures against internal damage inherent in the IWRC wire ropes were examined to overcome this serious problem and prevent further accidents.

2. ACCIDENT CASES

2.1 *Case 1: Fracture of Derricking Wire Rope*

a) Description of the accident

When the steel material of about 0.8ton were being hoisted by a 588kN crane in the building construction site, the wire rope having been used as jib derricking wire rope suddenly broke and the worker near that place was hit by the auxiliary jib and died on the spot.

b) Description of the wire rope and its failure condition

The fractured wire rope has a construction of IWRC 6×Fi (29) shown in **Figure 3** (a) in, with diameter of 16mm,and tensile strength 188kN having been used under the conditions shown in **Figure1**, with D/d =16 (D is the pitch circle diameter of sheave, and d is the rope diameter). The accident occurred eleven months after the wire rope replacement.

At the fractured portion, (1) distinct deformation of wire cross section, (2) internal wear due to the mutual compression and the rubbing between strand wires and core wire rope, and (3) many wire breakings of the cross section type with little elongation or necking are observed. **Figure2** shows an example of this kind of internal damage.

Most wires in core rope, many external wires, some internal wires of strands and all six core wires in them had broken with this type. However, in internal wires and core wires in strands, distinct deformation and wear were not observed. The precise observation by scanning electron microscope (SEM) disclosed that the above mentioned wire breaking of cross section type had occurred by fatigue crack initiation on the surface of wires and the following crack growth due to repeated rope bending at the sheaves.

The wires that kept effective strength until the moment of accident were only one third of internal wires of strands. The“ cup and cone ”type fracture different from the cross section type shows that they fractured at the accident not in fatigue but in static fracture mode. And the strength of the rope was estimated to be one tenth of the normal one. The external wear and wire breaking were not so extreme in comparison with internal ones. For example, the number of external wire breaking was about one forth of that of internal one at 1.5m from the fractured portion.

c) The cause of accident

The direct cause of this accident was the remarkable decrease of strength of derricking wire rope due to

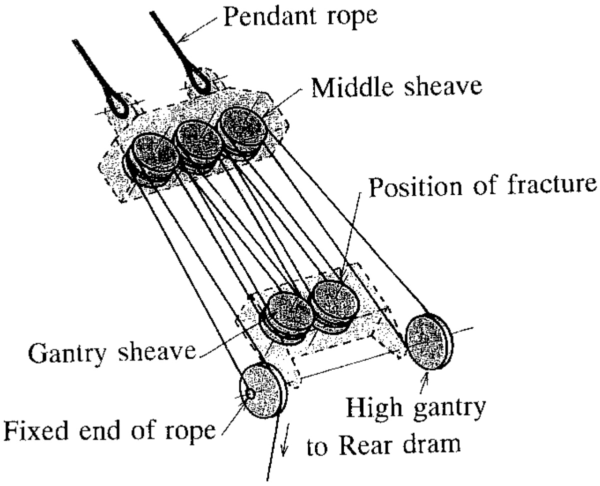


Figure 1: The path of derricking wire rope and fractured position

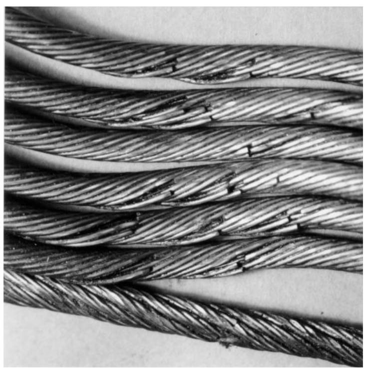


Figure 2: The feature of wire breaking inside the rope near the fractured portion

internal wear and the following fatigue failure. However, the intrinsic cause seemed to be that the damage had proceeded preferentially at internal portion and was very difficult to be found.

2.2 *Case 2: Fracture Accident of Hoisting Wire Rope*

a) Description of accident

The main hoisting wire rope of a crawler crane with a working capacity of 1470kN broke while hoisting a 44ton concrete block to be installed for a water break. The broken wire rope hit a worker on his head and he died instantaneously.

b) Description of the wire rope and working history

The wire rope was also an IWRC 6×Fi(29) with nominal diameter of 28mm and nominal breaking strength of 620kN and had been used for about 1.5 years.

c) The cause of accident

This accident was also caused by the extreme decrease of wire rope strength due to severe wear and excessive corrosion. Therefore, the primary or direct cause was improper management and inspection of the crane. However, almost all grease had been lost from the wire rope near the fractured portion and it was characteristic as a whole that the internal damage was heavier than the external one.

3. CHARACTERISTICS OF DAMAGE TO IWRC WIRE ROPE AND ITS PROBLEMS

3.1 *Characteristics of Damage*

a) Internal wear and fatigue wire breaking

Two examples of accidents due to the fracture of IWRC wire rope used as travelling rope were introduced. The Case1 is a typical example of fatigue failure with considerable wire breaking and the Case 2 is one with heavy corrosion. And both examples show that the internal damage played an important or essential role for the fracture. Similar results has been obtained by the precise investigation by the author on about ten cases and further by the experiment on similar ropes ［3］. Taking into account these results and also that the most typical internal wire breaking at the bed portion can’t occur in usual fiber rope core wire ropes, it may be predicted that IWRC wire ropes used as traveling ropes are prone to internal damage.

3.2 *Problems in Maintenance and Inspection*

As to the safe application of crane wire ropes, Japanese standard shows a guideline for the discard of damaged wire ropes. But it does not include the specific method of inspection, and so far the external observation by the naked eyes has been applied practically.

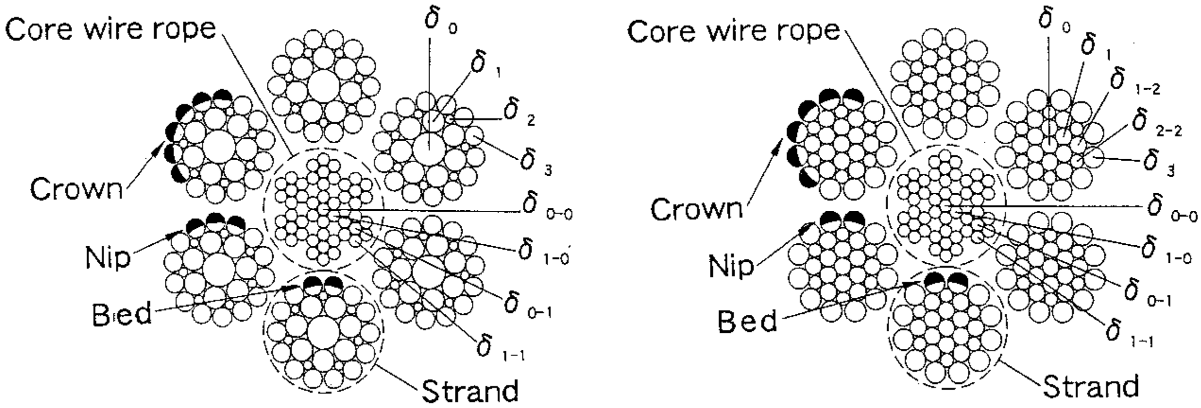
However, if the main damage exists inside the rope, it is impossible to detect them by this method, even if the level of damage exceeds the allowable limit. Therefore this method can't be said the appropriate inspection method as the last resort for safety assurance.

4. CERTIFICATION OF DAMAGE PROPERTIES OF IWRC WIRE ROPES

By the way, it has not been clear whether the prediction described above is correct or not, because the working conditions or history of working loads could not be confirmed for all accidents, and under such situation it would be difficult to focus the target of countermeasures to prevent the similar accidents. To improve such ambiguous situation, the following experiment was conducted at first to certify whether the remarkable internal damage as mentioned above could be formed even under the allowed loading conditions or not, and then to confirm the relations between the damaging conditions and the various testing conditions.

4.1 *Experimental Procedures*

Two kinds of wire ropes; IWRC 6×Fi (29) and IWRC 6×WS (31) were used for this experiment. Both ropes are of Ordinary lay type with red grease without plating, and their nominal ultimate breaking loads are equally 173.6kN. **Figure3** shows their construction. Fatigue tests were conducted mainly under cyclic S-



(a) IWRC 6×Fi (29) (b) IWRC 6×WS (31)

Figure 3: Construction of the test wire ropes

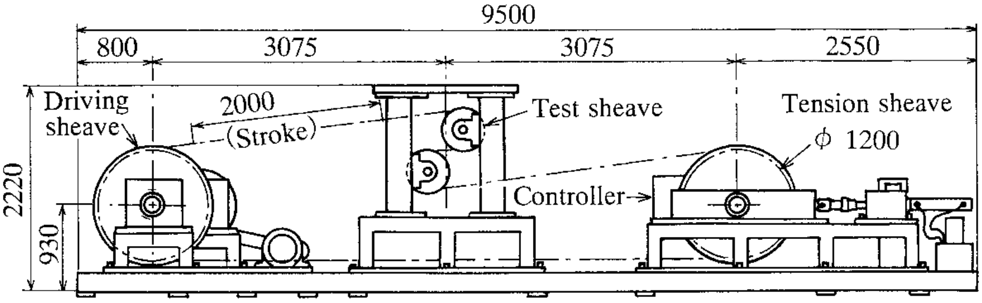


Figure 4: Wire rope fatigue testing machine

bending as shown in **Figure 4**, basically with D/d of 16, rope tension of 34.7kN and cyclic frequency of 10 cycles per minute. Moreover, fatigue tests were conducted with those conditions changed widely to clarify their effect on the rope damaging properties. Fatigue test were stopped when the number of external wire breaking in each rope pitch reached at 10 % of the number of strand wires, and the numbers of wire breaking in various positions (crown ,nip and bed) of strands were counted respectively for 20 pitches in the fatigued portion.

4.2 *Results and Discussion*

Figure 5 shows an example of the wire breaking distribution at various structural positions for IWRC 6×Fi (29) tested under the basic conditions described above. It is clearly that the number of internal wire breaking at bed and nip portions is more than that of visible wire breaking. The similar results were obtained for IWRC 6×WS (31) ropes, although wire breaking at nip portion was dominant in this case.

Figure 6 and **Figure 7** summarize the influence of various mechanical testing conditions including U-bending and some environmental conditions on the wire breaking distributions for both kinds of IWRC ropes, respectively. These results show that the internal damage was dominant or preferential to external ones, excluding for a few rare cases. There is no condition where damage is suppressed concurrently for both

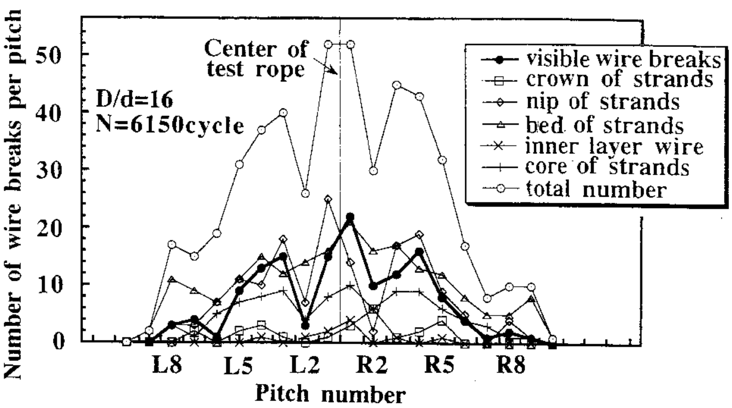
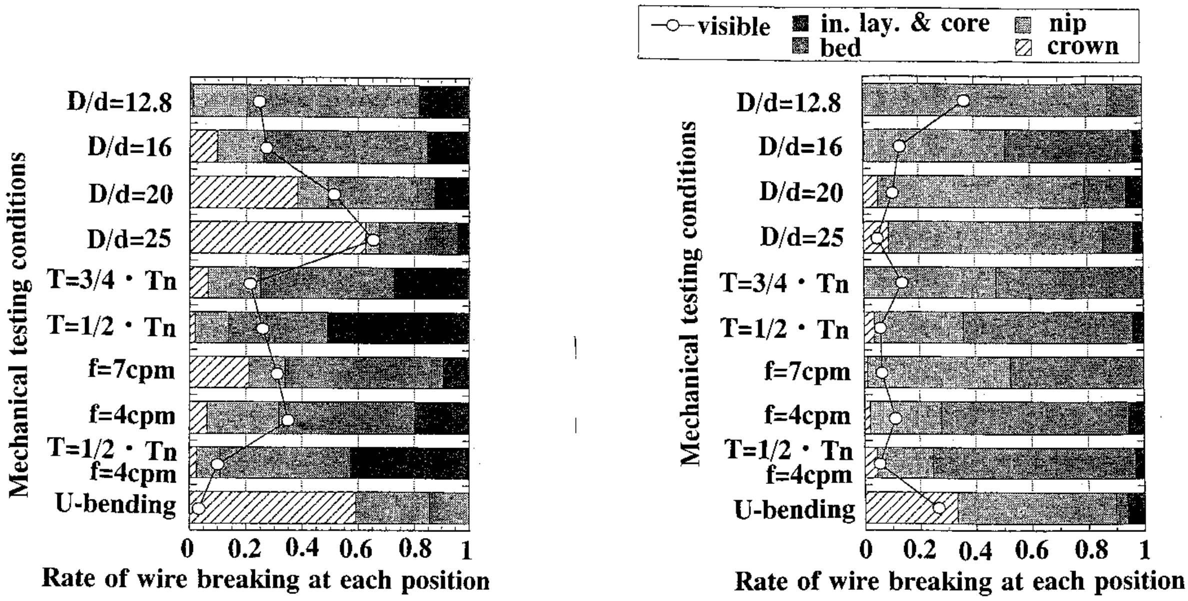
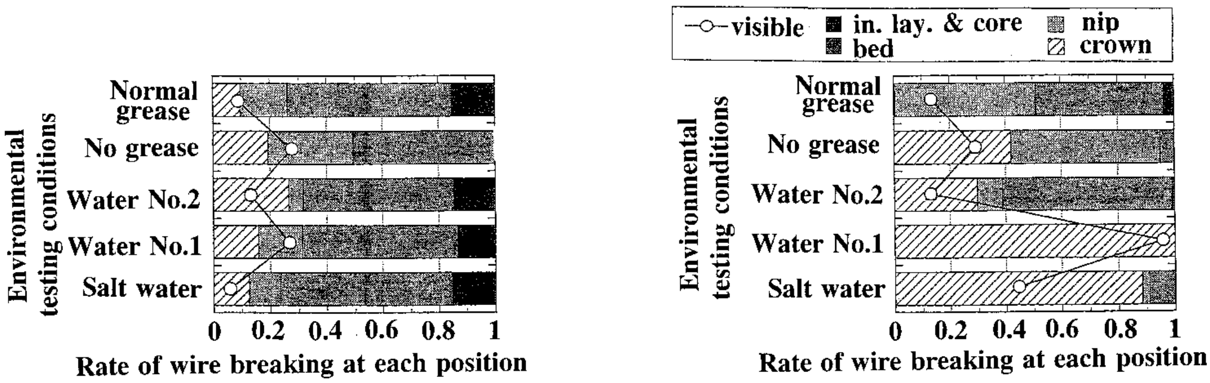


Figure 5: An example of wire breaking at various position in IWRC 6×Fi (29)



(a) IWRC 6×Fi (29) (b) IWRC 6×WS (31)

Figure 6: Influence of various mechanical conditions on the wire breaking distribution



(a) IWRC 6×Fi (29) (b) IWRC 6×WS (31)

Figure 7: Influence of various environmental conditions on the wire breaking distribution

kinds of ropes. From these results, it can be concluded that the prediction described in Section 3.1 is correct and the problem in maintenance and inspection pointed out in Section 3.2 exists actually. Therefore, it is natural to suppose that most of the recent rope fracture accidents as introduced in the section 2 were caused essentially because inspectors had not recognized clearly the significance of such internal damaging property of IWRC ropes.

5. MEASURES FOR THE PREVENTION OF IWRC WIRE ROPE FRACTURE ACCIDENTS

So far, there is no general or decisive countermeasure to prevent fracture accidents of IWRC ropes used as traveling ropes, and some temporary or second best measures have been proposed as followings.

(1) Direct observation of internal portion of the rope
By attaching clamp levers to both sides of the observation point of the rope and loosening the rope by them, the internal damages can be observed directly if there exist distinct ones ［4］.
(2) Making the discard standard more strict
When only the external inspection is cited inevitably, the rope should be discarded if any or a few, for example, one or two wire breaking was detected.
(3) Shortening of working period
In the case where a rope has been used for a fairly long period and there is no reliable data for working period, the rope should be replaced soon as a temporary measure, and precise damage investigations are

recommended in order to decide the reasonable replacing period for the following wire ropes. It will be more effective if the aforementioned three measures are combined.

(4) Getting rid of factors contributing to the internal damage

Unfavorable factors to prevent the internal damage, such as small D/d, overloading and extreme rope-pattern wear on the surface of sheave groove should be eliminated.

(5) Sufficient grease supply

It is necessary to supply sufficient grease to wire ropes especially of IWRC type when they are used in the corrosive environments such as sea water and so on.

(6) Development of inspection methods and devices

It is strongly expected that new procedures or instruments with the sufficient reliability and theease of treatment for practical use will be developed at low cost.

(7) Standardization of method of wire rope diameter measurement

It seems possible to use the decrement of rope diameter as a measure for discard if the measurement conditions are properly decided, for example, such as "under a constant extension force".

(8) Precise analysis of properties of damage

As decisive or final measures to improve the present situation , it is necessary to investigate the damage properties for this kind of wire ropes systematically.

As the result of the studies by concerning persons (Ministry of Labor, Japan Crane Association, rope makers and crane users) and the performance certification tests by the author on a new commercial rope tester, two concrete countermeasures were selected and recommended as realistic ones.

The first one is "the simple inspection manual for crane wire ropes" proposed by Japan Crane Association. This is a combined method of measure *(2)* and other ones, in which the simple naked eye's observation method with discarding level more strict than usual ones (for example, provided in Crane Structure Code) for various kinds of damages is adapted first, and the rope with higher damage level should be discarded or checked if it can be used further safely, by means of more reliable inspection methods.

The second one is an electro-magnetic damage inspection method using new detecting apparatus developed recently by a rope maker in Japan. According to the study on its detecting ability of internal wire breaking, it has realistically satisfactory performance for checking the safety of IWRC wire ropes.

6. CONCLUDING REMARKS

Damaging properties of IWRC wire ropes were investigated by means of case studies and wide range of S-bending fatigue experiments, and countermeasures were examined to prevent the possible accidents caused by the internal damages of this kind of wire ropes. Main result obtained are summarized as follows.

(1) From the results of the precise analysis of crane accidents caused by the fracture of wire rope, it was predicted that IWRC ropes were prone to internal damage.
(2) The results of extensive fatigue experiments showed that the prediction described above was correct, which means that the present situation would be serious because the wire rope inspections commonly completed by visual observation of external features would not reveal internal damage.
(3) To improve such situation, several countermeasures against internal damage inherent to the IWRC wire ropes were examined, and two practical methods were recommended. The first one is "the simple inspection manual for crane wire ropes", and the second one is the application of electro-magnetic damage detecting apparatus recently developed.

REFERENCES

1. Tanaka, M.(1989). Report on Jib Falling Accident in Dock Crane (in Japanese).
2. Tanaka, M.(1995). Mining and Material '95, Proceeding for Wire Rope (in Japanese), pp.36- 38.
3. Gibson, P. T. et al. (1974). Final Report to Naval Ship System Command.
4. ISO 4340-1990, Annex D, Internal Examination |of Wire Rope, pp. 11-12.