Development of Prevention System from Hitting For Hydraulic Excavators

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Abstract

Fatalities caused by industrial accidents in the construction industry have remained level since the first half of the 1980s. The majority of these fatalities are caused by falls, contact between workers and construction equipment, or by overturning construction equipment. This project was undertaken to study the hitting between workers and construction equipment, and develop technology to improve the safety of construction equipment etc. in order to prevent accidents in the construction industry. Specifically, new hitting prevention technology has been developed by proposing and studying a detection system consisting of ultrasonic sensors (transponder mode) as a new technology to prevent hitting between workers and construction machinery, and by conducting performance tests and studies of its applicability to actual construction sites to confirm its safety and usability.

1. Introduction

Accidents caused by construction equipment that now occur on construction sites include workers falling off equipment, hitting between workers and machinery (struck violently by equipment, crushed between equipment, caught in equipment), and overturning accidents. Up till now, worker education and improved safety technology for construction equipment have been provided in an effort to prevent such accidents. A study conducted by the Industrial Safety and Health Department of the Ministry of Labor shows that the number of fatalities caused by industrial accidents in the construction industry fell steadily to 927 per year in 1986 thanks to the efforts of construction companies and other concerned organizations. But as Figure 1 shows, the fatality level has crawl sideways since 1986.

Industrial accidents caused by construction equipment have been the second most frequent category of accident with falls the most common.

An examination of categories of industrial accidents in the construction industry shows that many of these accidents are either falls or are caused by construction equipment.

This research and development project, one conducted to develop and propose new hitting prevention technology, involved the proposal and study of a worker - construction equipment contact prevention system equipped with ultrasonic sensors as a new technology that will improve the safety of construction equipment in order to prevent construction site accidents, accompanied by testing of its performance and a study of its applicability to actual construction sites in order to confirm its safety and usability.

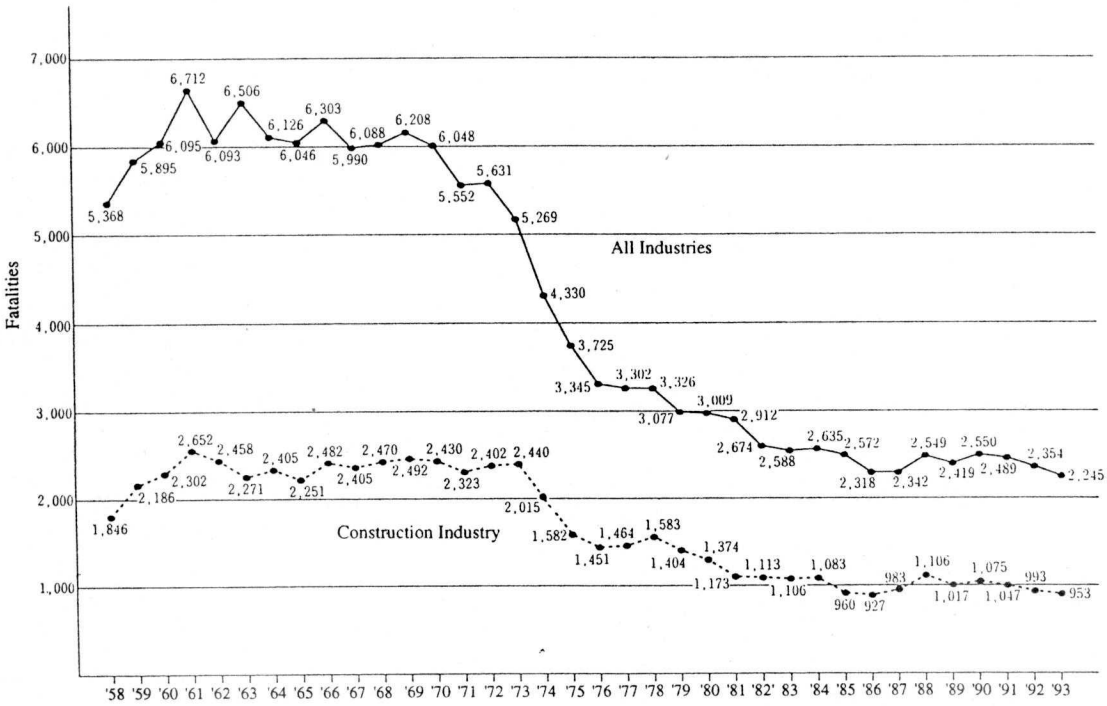

Figure 1 Numbers of Fatalities From Industrial Accidents
(From the Construction Industry Health and Safety Annual of 1994)

The report presents the results of a joint study carried out in 1993 and 1994 by nine participants, the Ministry of Construction, the Japan Construction Mechanization Association, Kato Works Co., Ltd., Kobe Steel, Ltd., Komatsu Ltd., Shin Caterpiller Mitsubishi Ltd., Sumitomo Construction Machinery Co., Ltd., Tokimec Inc., and Hitachi Construction Machinery Co., Ltd., as part of the Comprehensive Technology Research Project of the Ministry of Construction: the Development of New Execution Technology for the Construction Industry.

2. Construction Machinery Included in the Study

According to the Construction Industry Health and Safety Annual, accidents caused by construction equipment are broadly categorized as workers falling off equipment, hitting (struck violently by equipment, crushed between equipment, caught in a machine).

The 1994 Construction Industry Health and Safety Annual (Table 1) indicates that the category of construction machinery involved in the most fatalities are hydraulic excavators, which are a factor in 58.6% of all fatal accidents, followed by rollers, the cause of 11.1% of the year's fatalities.

These accidents occur most frequently during road work and land readjustment.
Consequently, the construction equipment category selected for this worker - construction equipment hitting accident prevention system research and development project carried out to provide improved safety measures for construction equipment was hydraulic excavators: the type of construction equipment responsible for more accidents than any other as well as the most common type of construction machine in Japan, accounting for more than half (approximately 640,000 units) of all construction machinery owned in the country (approximately 990,000 units).

Table 1 Fatalities Involving Construction Machinery

Work Category / Accident Category	Civil Engineering												Building Construction	Equipment Work	Totals
	Electric Power Dam	Tunnel	Subway	Railway	Bridge	Road	River	Erosion Control	Land Readjustment	Sewer/Water Supply System	Harbor	Others			
[1] Belt Conveyor Etc.	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
[2] Battery Car, Trolly,, Etc.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[3] Bulldozer Etc.	0	0	0	0	0	1	0	0	6	1	0	2	1	0	11
[4] Hydraulic Excavator Etc.	0	2	0	0	1	23	7	5	14	7	0	17	12	1	89
[5] Pile Driver/Extractor	0	0	0	0	0	0	1	0	0	1	1	1	0	0	4
[6] Roller Etc.	0	0	0	0	0	11	1	0	3	1	0	0	0	1	17
Self-propelled Construction Equipment Other Than [1] to [6]	0	1	0	0	0	1	1	0	3	0	0	2	7	3	18
Others	1	1	1	0	0	2	0	0	0	0	1	1	3	1	11
Totals	1	4	1	0	1	38	10	5	26	10	2	23	24	7	152

Construction Industrial Accident Prevention Association "1994 Construction Industry Health and Safety Annual"

3. Purpose of the Development

The development project was conducted in order to provide technology to prevent hitting accidents between construction equipment and workers on construction sites by developing a practical system using existing ultrasonic warning equipment with improved detection precision and enhanced usability for use on hydraulic excavators: the most common type of construction equipment in Japan.

4. Existing Technology

Ultrasonic warning equipment has already been developed for use as a hitting accident prevention system, but has not come into wide use. However, nationwide, about 300 road rollers, tire rollers, etc. are equipped the systems shown in Figure 2 to detect (alarm function only) presence of persons.

And safety apparatus for use on rotating type construction machinery (hydraulic shovel type) shown in Figure 3 has been developed. It detects and automatically shuts (emergency stop function) off the machine if it detects a worker in the detection area . This technology is also not in wide use; it reduces work efficiency because the detection range is wider than the area where work is actually being performed and because the emergency stop function creates the danger of secondary accidents.

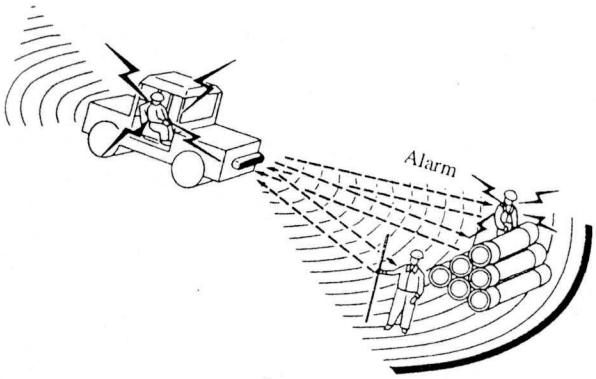

Figure 2 Commercially Available Contact Prevention Device (Example)

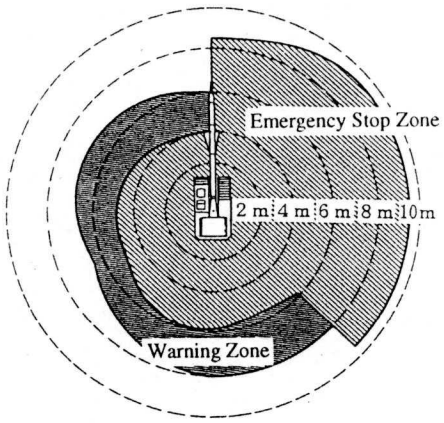

Figure 3 Sensor Detection Range (Technical Evaluation System)

4.3 Be in great fear, be startled Fact-finding Study

An on-site fact-finding survey (be in great fear, be startled survey) was conducted to find out what part of a hydraulic shovel poses the most danger to nearby workers. Conducted at 36 membere companies of the Construction Industry Sub- committee of the Japan Construction Mechanization Association (Table 3), the survey provided the following results.

1) The study of the locations of be in great fear, be startled revealed that be in great fear, be startled are extremely common at two locations: 40.2% are around the bucket and 41.8% around the back of the rotating part of the excavator, as shown in Figure 4.
2) At the back of the rotating part, be in great fear, be startled were more frequent on the right side than on the left side.
3) When be in great fear, be startled occurred, the hydraulic excavators were most frequently turning (73.0%), followed by moving (15.3%), with rotating the bucket last (8.8%).

Table 2 Cases Surveyed (Persons)

Operators	Workers	Superintendents	Total
434	263	230	927

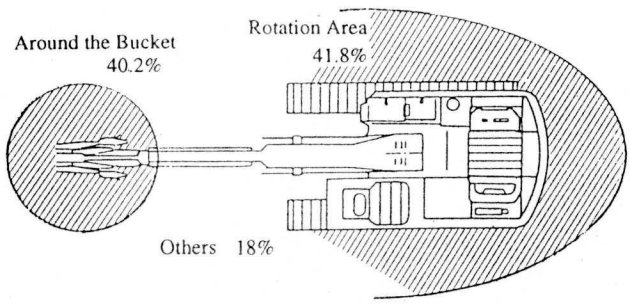

Figure 4 Be in great fear, be startled parts

5 Structure of the System

5.1 Concept of the System

Based on existing technology and the results of the fact-finding survey, the hitting prevention technology needed to provide both operating efficiency and safety was developed in accordance with the following concepts.

1) Detection with sensors would only be done in the operator's dead angle.
2) The system would not interfere with work when a worker must be near the construction machine to perform required tasks.
3) Three zones would be provided by establishing a distance within which it will be necessary to activate the emergency stop function and treating the area within that distance as the emergency stop zone, establishing a speed reduction zone outside the emergency stop zone, and providing a warning zone as the outermost zone.
4) The alarm function, or normal operation, deceleration, and stopping will be activated only when the operator is manipulating the operating levers.

5.2 Basic System Proposal

The system shown in Table 3 and in Figure 5 was proposed in accordance with the development goals.

The contact prevention technology developed and proposed will, by sharply narrowing the existing detection range and adopting the warning, deceleration, and stop zone approach, guarantee safety while not interfering very much with the progress of the work (it will be practical and usable in real construction sites). The sensor technology to be used for detection purposes will be ultrasonic sensors (transponder type) because this type is easy to use and economical.

With this transponder type ultrasonic sensor system, ultrasonic sensors installed on the machine and in helmets worn by workers on the site will transmit sound waves back and forth to detect the location of all workers. This approach provides far more reliable detection and greater precision than reflection type ultrasonic sensor systems.

Table 3 Ultrasonic Sensor Detection And Alarms (Proposal)

Function \ Detection Zone	Moving Zone Back and Right (Moving Sideways)	Rotating Zone Right and Left Sides	Work Apparatus Zone Around the Bucket
Alarm Zone (Displayed on the Monitor)	4m	4m	None
Deceleration Zone (Lights flash on monitor and an alarm sounds)	None	2m	None
Emergency Stop Zone (Lights flash on monitor and an alarm sounds)	2m	1.5m	3m
Number of Sensors	4	2	2
Forced Stop Release Switch	None	None	Yes (Always in forced stop status when the power is turned on)

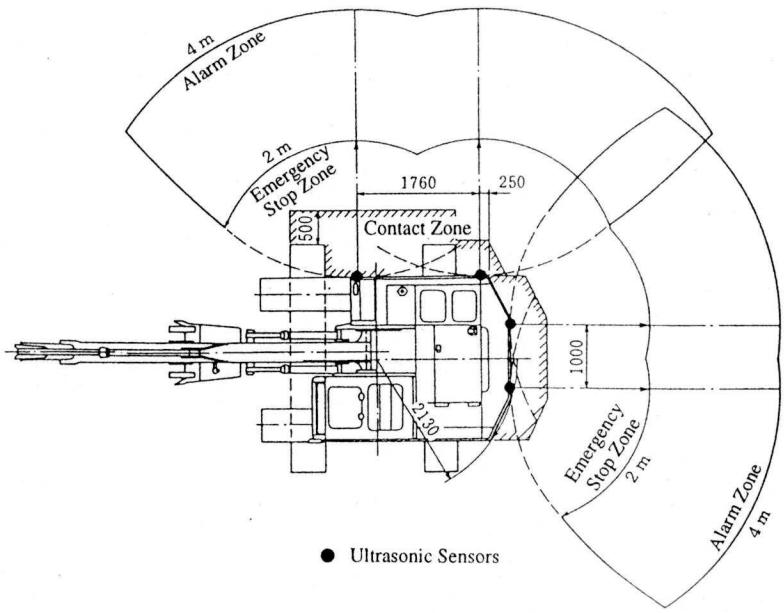

Figure 5 Detection Zones of the Newly Developed Technology (Moving Mode)

5.3 Performance Testing

The performance testing shown in Photograph 1 was conducted on the grounds of the Public Works Research Institute based on the proposed basic system. The results confirmed the detection range shown in Figure 6, and demonstrated that the test system provided performance almost identical to that of the proposed basic system.

Photograph 1 Performance Testing (Construction Machine test field)

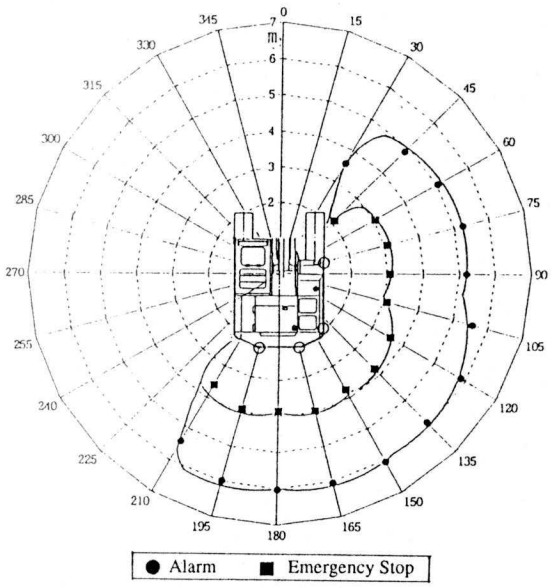

Figure 6 Detection Range (Measured Values)

5.4 Applicability to Actual Construction Sites

In order to determine how practical it would be to use the newly developed system at actual construction sites, the system was tried out for a period of two weeks at each of three sites such as the one shown in photograph 2 in order to study the safety and work efficiency that could be achieved using the system.

Photograph 2 Trial Site (Example)

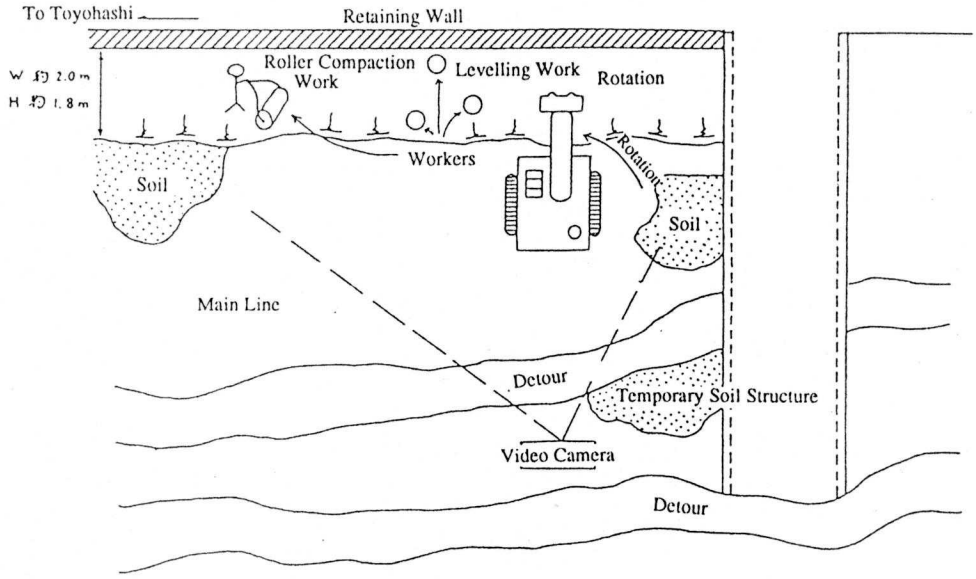

Figure 7 Work Conditions and Video Camera Location (Example)

Video cameras etc. were used for about two days at each trial site in order to obtain a record of the way that hydraulic excavators are used, the operation of the contact prevention equipment, and the state of the workers.

Figure 8 shows the operating status of the system when used on a site, and Figure 9 shows the proximity locations when deceleration and emergency stops occurred.

Figures 8 and 9 show that deceleration and emergency stops occurred frequently at the front, but these were cases in which the stop occurred when a worker walked in front to give a work signal to the operator.

The study also confirmed that in addition to the front area, the system operated during work accompanying rotation in the operator's dead area.

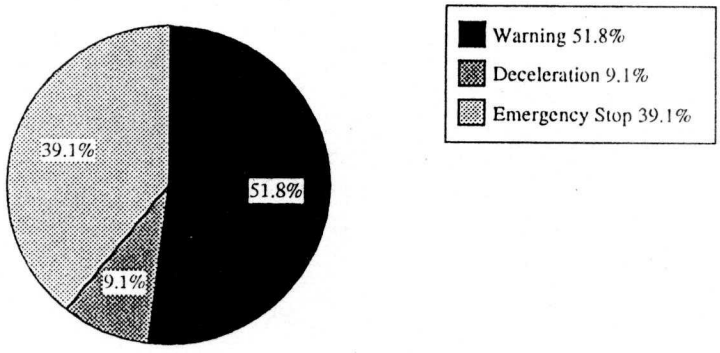

Figure 8 Results of Contact Prevention Device Operation at the Site

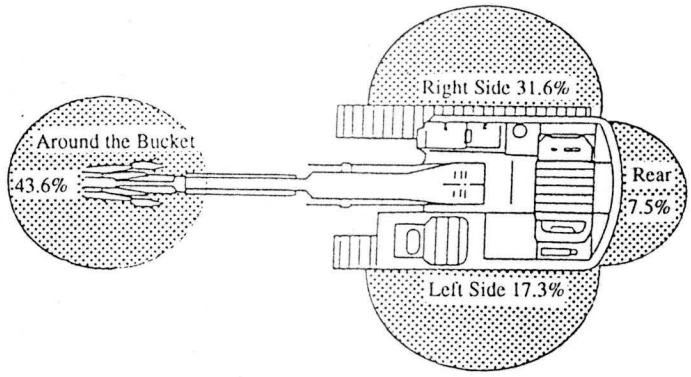

Figure 9 Proximity Location When Deceleration and Emergency Stop Occur

The following facts were clarified through interviews with the superintendent, operator, workers, and the induce.

1) There was little decline in work efficiency.
2) Because a lot of work is done close to the bucket, it was a little inconvenient to use on site.
3) Safety improved because the operator and the workers had to check many things in order to use the system.

The participants also reported that by using the system for about two weeks on site, they became accustomed to handling the equipment (sensors), and the unfamiliarity they felt at first completely disappeared.

6. Summary

Through this research and development work, a system was developed that prevents worker - construction equipment hitting accidents to eliminate danger on construction sites. Testing of the basic features of the newly developed hitting prevention type hydraulic excavator has clarified that it satisfies the specifications (detection range, detection performance, etc.) established at the study stage and will perform exactly as planned.

The results of two weeks of on-site trial operation of the hitting prevention type hydraulic excavator which had already passed its basic performance testing revealed a few problems: a slight decline in work efficiency (particularly when work is conducted around the machine), the need for the operator to become accustomed to operating the ultrasonic sensors, and problems handling the operating levers after an emergency stop (the operator did not know what to do after an emergency stop occurred), but when improvements have been completed, it will be possible to use it at real construction sites.

Based on a study of the economic factors, at the research and development stage, the target is a price that does not exceed 10% of the total cost of a 20-ton class hydraulic excavator, but costs will likely fall further at the mass production stage.

7. Conclusion

Hitting prevention technology for construction equipment was used to develop and study a working system (transponder type ultrasonic sensor), but this newly developed technology can not be counted on to prevent all hitting accidents. Operators and other workers must be fully knowledgeable and aware of safety matters as they work; this technology is only intended to serve as a back-up.

The next step will be to prepare for the wide introduction of the system by carrying out more studies of its practicality at many construction sites in order to continue technical development work until it is at the stage where it guarantees safety without interfering with construction work (achieves usability and safety). This will be followed by efforts to popularize its use.

It will be necessary to handle the system created through this research and development work according to circumstances after a decision is reached concerning the way in which future international standards now under study will be finalized as ISO/TR9953 standards. However, a forward-looking attitude must be adopted and work continue to improve safety regardless of the ISO.

In conclusion, the authors would like to express their gratitude to the members of all those organizations that assisted with the fact-finding survey and test executions conducted as part of this research and development project: the Iwaki National Highway Construction Office and Tohoku Technical Office of the Tohoku Regional Construction Bureau, the Utsunomiya National Highway Construction Office, Sagamu National Highway Construction Office, Joban Construction Office, and Kanto Technical Office of the Kanto Regional Construction Bureau, the Hamamatsu Construction Office, Chubu Technical Office and Construction Mechanization Research Institute of the Chubu Regional Construction Bureau, and the 36 member companies of the Construction Industry Sub-committee of the Japan Construction Mechanization Association.