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Safety Control for Large-Scale Underwater Blasting

Contrôle de la sécurité pour les travaux sous-marins réalisés à l'aide d'explosifs

Sicherheits-Überwachung bei grossen Unterwasser-Sprengungen

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SUMMARY

This paper deals with the safety control for large-scale underwater blasting, based on the findings of the Honshu-Shikoku Bridge Authority from the preliminary surveys, studies, technology developments, of the measurements taken while blastings were in progress, and from surveys and inspections of the field plants.

RÉSUMÉ

L'article traite du contrôle de la sécurité pour les travaux sous-marins de grande envergure réalisés à l'aide d'explosifs. Il se base sur les constatations faites par les Authorités des Ponts de Honshu-Shikoku à partir d'études préliminaires, études et développements technologiques ainsi qu'à partir des mesures effectuées en cours de réalisation et l'étude des installations sur le terrain.

ZUSAMMENFASSUNG

Der Beitrag befasst sich mit der Sicherheits-Überwachung von grossen Unterwasser-Sprengungen beim Bau der Brücken des Honshu-Shikoku-Projekts. Er stützt sich auf Voruntersuchungen, Studien, technische Entwicklungen, Messungen während Sprengungen sowie auf weitere Untersuchungen und Inspektionen vor Ort, die von der Bauherrschaft durchgeführt wurden.

1. OUTLINE

Of the 19 foundations built underwater to support the Kojima-Sakaide route of the Honshu-Shikoku connecting Bridge, blasting was carried out for 8 foundations, at water depths from 0 to 35 meters with tidal current speeds of 2 to 5 knots per hour, using a drill mounted on a self-elevating platform (SEP). Table 1 shows details of the drillings, chargings and blastings carried out.

Features of the North-South Bisan-Seto Bridge are that it is an extremely long, dual suspension bridge designed to straddle the Bisan-Seto traffic route. The structures of its undersea foundations are gigantic. Construction of foundations 6P and 7A could have affected the overall construction period and was hence very important. Other than strict observance to the established construction period, effort had to be made to make sure the following locational and other restrictions did not affect the success of the underwater blastings.

1. Distances of 250 to 600 meters offshore of the Bannosu district, water depths of 14 to 35 meters, and tidal speeds of 2 to 3 knots per hour.
2. Underwater blastings could not be allowed to affect the Asia Kyoseki Sakaide Refinery located adjacent to the Bannosu north revetment.
3. Commercial operation of the refinery was started in 1972. Its production capacity at the time of blasting for foundation 7A in 1979 was 80,000 bbl/day. A production increase up to 100,000 bbl/day was planned at the time of blasting for foundation 6P performed between 1980 and 1981.

Name of bridge		North-South Bisan-Seto Bridge					Iwakurojima Bridge		Hitsuishi-jima Bridge
Site		3P	4A	5P	6P	7A	3P	4P	2P
Depth (m)		-10	-10	-32	-50	-50	-24	-14	-28
Dimension (m)		23x57	57x62	27x59	38x59	75x59	22x46	36x32	24x46
Depth of water (m)		0~5	0~5	22~25	33~35	14~22	3~20	2~10	9~25
Current (knot)		5	5	5	3	2	5	4	4
Depth of drilling (m)		-10	-10	-31.5	-49.5	-49.5	-24	-14	-27.5
Total holes		663	1189	504	768	1632	572	832	432
Drilling interval (m)		2x2	2x2	2x2.2	2x2.25	1.8x 2.25	2x2	2x2	2x2.5
Firing		DF	DF	US	EM	EF	DF	DF	EM
Inst. or delay		I	I	I	I	D	I	I	I
Charge (kg)	Max.	2240	3000	2016	1080	1440	1356	1279	480
	Min.	672	720	480	360	960	550	800	240
Total charge (t)		23.5	41.5	12.1	16.3	36.0	17.3	15.0	10.2
Time		15	19	8	21	32	15	13	33
Term		1979.2~ 1980.5	1979.1~ 1980.9	1979.1~ 1979.6	1980.11~ 1981.5	1979.1~ 1979.11	1981.11~ 1982.4	1982.5~ 1982.10	1983.2~ 1983.9

DF: Detonation fuse method
US: Ultrasonic wireless method
EM: Electromagnetic wireless method
EF: Electric firing method
I: Instantaneous firing method
D: Delayed firing method

Table 1 Performance results of underwater blasting

2. TECHNOLOGICAL METHODS FOR SAFETY CONTROL

2.1 Basic policy

At the time of implementing the underwater blasting program in 1971, the authority gave full recognition that it was a matter of cooperation between academic and industrial knowledge, so it commissioned the following organs to 20 preliminary surveys, studies and technological developments so that the large-scale underwater blastings for the foundations of the North-South Bisan-Seto Bridge could be carried out with safety and certainty: The foundation work was the critical area for the entire 9-year construction period.

The Research Institute for Safety Engineering (RISE):
Undertook surveys, studies, and the basic planning of the underwater blastings and issued instructions on measuring techniques.

Japan Industrial Explosives Association:
Mainly concerned with confirmation of explosives performance and instructions on explosives handling techniques.

2.2 Safety control system during work progress

Throughout the long period during which underwater blastings were carried out, surveys were conducted in the vicinity of the centers of blasting, measurements of the underwater pressures and ground vibrations were taken, and surveys and checks on the refinery installations were conducted both before and after each blasting. The data thus obtained was analyzed as speedily as possible. Each blasting followed a discussion meeting participated in by experts from the Research Institute for Safety Engineering, responsible persons from Asia-Kyodo Oil Co., Ltd. and engineers from the contractors and the authority.

The aim of these meetings was to check the results of measurements taken at each blasting so that the extent of the influence of the blasting on the neighboring environment could be discussed and influence decisions to be made for the subsequent blasting program and its implementation. The employment of such a discussion system made it possible to predict the safety of underwater blastings with a certain amount of certainty. The system, therefore, could be considered a technological method effecting the overall safety control of the field work.

3. SURVEYS, STUDIES AND TECHNOLOGICAL DEVELOPMENTS CARRIED OUT BY THE AUTHORITY

3.1 Outline of the 1971-1974 period

This period was slanted mainly toward developing explosives and confirming their performance, as well as conducting a water-tank experiment and in-situ experiment to estimate the influence of underwater pressure and ground vibrations. The first experiment conducted in the Omishima area was intended to confirm the performance of the developed explosives and accessories and for surveying the feasibility of employing the drilling-blasting method using an SEP. Subsequently, computer-aided programs were developed to predict the blast effect from underwater blasting and its influence on the vicinity, which followed in-situ experiments to improve prediction accuracy.

Figure 1 shows the simulation and measured values obtained at a measuring point about 600 meters from the underwater blasting center (about 1 ton) carried out for foundation 6P. The simulation value 2 cm/sec is somewhat higher than one measured value 1.35 cm/sec, but biased on the side of safety as an estimation value used to control the work.

3.2 Outline of the 1975-1979 period

This period was slanted toward selecting, prior to commencing the actual work, the optimum method of underwater blasting and for studying the safety of the

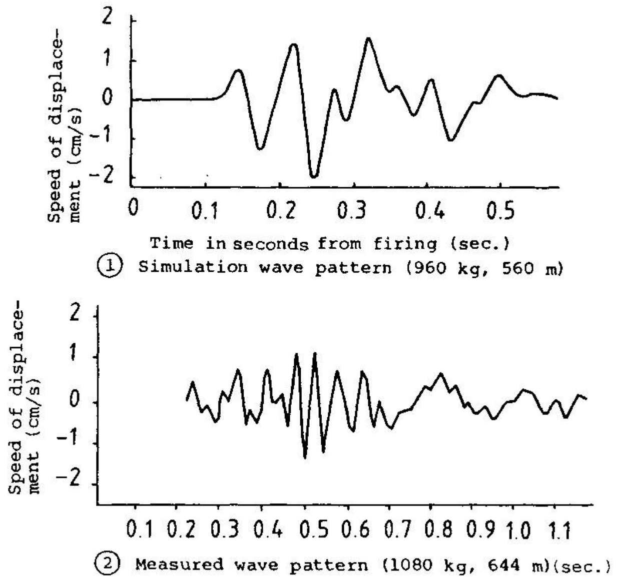

Fig. 1 An example of ground vibrating wave pattern

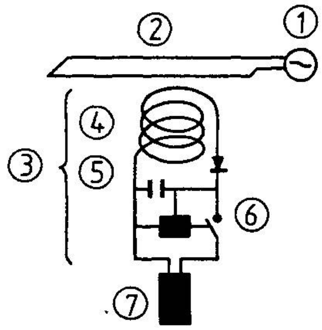

Fig. 2 Schematic diagram of the blaster; ① Oscillator, ② Exciting loop, ③ Blaster, ④ Pick up coil, ⑤ Firing condenser, ⑥ Electric switch, ⑦ Cap.

refinery installations. The offshore test work carried out in 1975 was concerned with the detonation fuse method and delayed firing method to establish drilling, charging and blasting methods and their influence on the adjoining refinery. Subsequently, surveys on the response of the instruments were conducted in the compound of the refinery to study how to secure the refinery installations during the progress of constructing permanent foundations 6P and 7A.

In order to decide the optimum method of firing for foundation 6P, an onshore experiment was conducted to confirm the electromotive force of the electromagnetic firing element. Figure 2 shows a schematic diagram of the electromagnetic firing method. Table 2 shows the contents of surveys and studies concerning the underwater blasting.

Years	Survey item	Development item	In-site experiment and item
1971 ~ 1974	① Performance of explosives and accessories. ② Feasibility of blasting the free side alone. ③ Influence of underwater pressures and ground vibrations on vicinity. ④ Damage to aquatic life and how to reduce it. ⑤ Effect of bedrock blasting. ⑥ Influence on refinery installations.	⑫ Dynamite GX-1, booster, cartridge and other accessories. ⑬ Computer-aided simulation.	Omishima experiments: ①, ②, ③ and ⑫. Water-tank experiments: ④ Bannosu onshore experiments I: ⑤, ⑥ and ⑬

Cont'd

Years	Survey item	Development item	In-site experiment and item
1975 ∽ 1979	⑦ Detonation fuse method and delayed firing method. ⑧ Safety of refinery installations. ⑨ Electromotive force of electromagnetic firing element.	⑭ Overburden blasting method. ⑮ Explosives handling manual. ⑯ Electromagnetic firing method.	Offshore test work: ⑤, ⑥, ⑦, ⑭ and ⑮ Experiment at refinery compound: ⑧ Bannosu onshore experiment II: ⑨ and ⑯
1979 ∽ 1981	⑩ Measuring of blasting influence. ⑪ Surveys and inspections of refinery installations.	⑰ Safety control system.	Actual work: ⑩ ⑪ and ⑰

Table 2 Surveys, studies and technological developments concerning underwater blasting

4. SAFETY CONTROL FOR LARGE-SCALE UNDERWATER BLASTINGS

4.1 Safety control system

In order for the underwater blasting work for foundations 6P and 7A to be completed safety and securely and in the minimum possible period, it was necessary to establish as large an area as possible for each blasting to make the areas to be blasted uniform, i.e. it was necessary to plan for the largest possible blasting. As the test work in 1975 made clear, the sensitive response of the refinery to the blasting vibrations, from the programmed blastings for actual works (foundations) carried out, first with small amounts of explosives, while confirming their safety, before making the scale of blasting larger.

The objective of discussion meetings was to make an overall analysis of the various data resulting from each blasting so that the safety of the refinery installations could be secured, and that, in addition to confirming the safety of the refinery installations, the conclusions on the amount of explosive for subsequent blasting, the method of measurement, and the time for blasting could be fed back to the works immediately. Table 3 shows the work performance organization by which the underwater blasting work for foundations 6P and 7A could be carried out in safety.

4.2 Measuring of blasting influence

To analyze the extent of the influence of a blasting on the refinery installations, it was necessary to measure the ground vibrations exactly in places where the structures are located. To enable the measuring work and data consolidation to be done efficiently, 6 points were established for measuring ground vibrations, 3 points for structural response and another 3 points for underwater pressures, with consideration given to the distances from the centers of blasting and the types of structures to be secured. These measuring points were established for 7A following the commencement of the blasting work. For the blasting for 6P, the displacements of the compressors and turbines caused by blasting vibrations were added. Figure 3 shows the locations of the measuring points within the refinery installation.

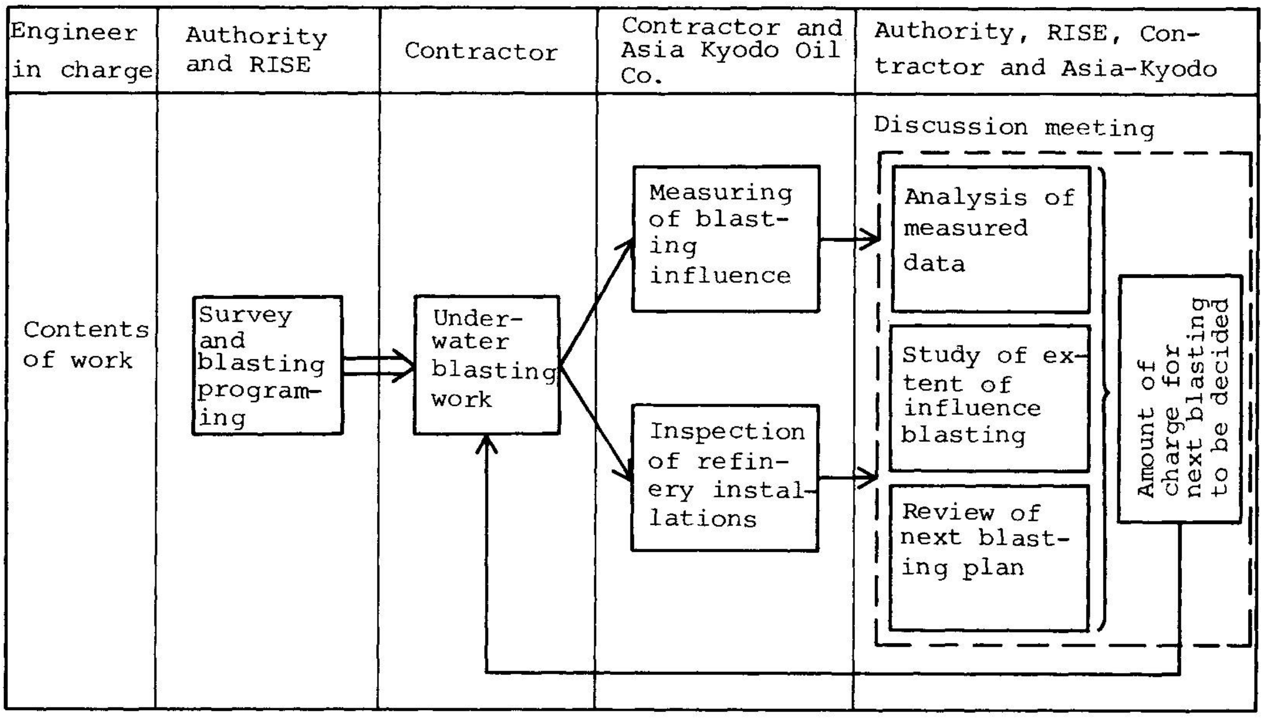

Table 3 Underwater blasting work performance organization for 6P and 7A

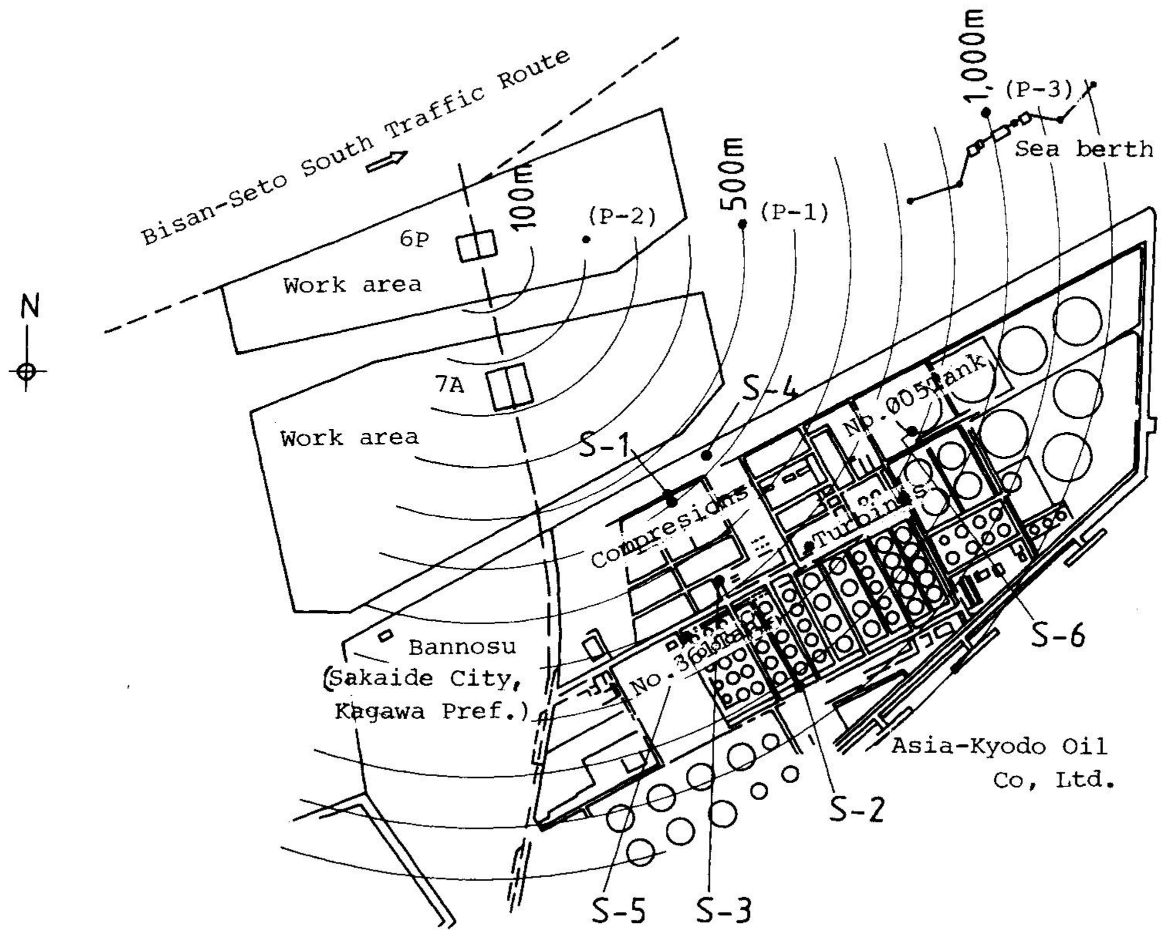

Fig. 3 Locations of measuring points

4.3 Results of refinery installation surveys and inspection

Past survey findings indicate that the aseismatic resistance of the refinery installations are problematic in that the instrumentation system consisting of level gages, flowmeters, pressure gages and other instruments malfunctions sometimes, partly due to the locations of the instruments in place and their supporting methods. For this reason, with the cooperation of the oil company, instruments were installed by means of an improved method, and safety inspections using a check sheet were conducted before and after each subsequent blasting. Table 4 shows the total number of the instruments suspected to have been affected by the blastings for 6P and 7A, and the maximum ground vibration values measured at points S_1 and S_5. Those effected by blasting are the instruments indicating some fluctuations in their commands and records, and they include those which showed secondary response to erroneous signals transmitted from the instruments affected.

Judging from the findings of the influence from the blastings and from the findings of surveys and inspections of the refinery installations, none of the instruments themselves was damaged, and therefore the blastings had virtually no effect on the operation of the refinery.

Site	Instrument affected by blasting	Maximum ground vibration value (Vertical component)	
		S_1 (distance)	S_5 (distance)
6P	74 units	1.9 cm/sec (650 m)	0.9 cm/sec (860 m)
7A	90 units	2.6 cm/sec (365 m)	1.0 cm/sec (580 m)

Table 4 Survey and inspection results of refinery installations

5. CONCLUSION

Underwater blastings for foundations 6P and 7A were able to be successfully completed 53 times without accident or disaster. However, the inspection of the refinery installations conducted after the 15th blasting for 6P showed that one of the heating pipes inside the reheating furnace for the kerosene desulfurizing equipment was disconnected from the guide support. The amount of explosives was reviewed at a discussion meeting held after the blasting to produce more intensified observation measures, and others, to be reflected in subsequent blastings.

The safety control system implemented this way before and after each blasting was perfect, and made it possible to discover influence on the refinery installations at the early stage, leading to the successful employment of effective measures and to a possible shortening of the long-term construction period.

The technological methods of handling such a safety control system was usefully employed in subsequent blastings for the Honshu-Shikoku Bridge Project, leading to the completion of all the blastings without accident as shown in Table 1.

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