*Costa de Benalmadena — Malaga*

# PART III

# COASTAL STRUCTURES

*Playa D'Aro — Gerona, costa Brava*

# CHAPTER 147

## GENTLE SLOPE SEAWALLS COVERED WITH ARMOUR UNITS

by
Osamu Toyoshima

ABSTRACT

Since the early 1960's, many seawalls against the beach erosion have been constructed in Japan, most of which were of vertical type. As a result, some of the seawalls even encouraged the beach erosion due to the reflected waves on the steep front of the seawalls. The author then proposed seawalls of new types with gentle front slope(1 to 3) covered with armour units in 1981, and over one hundred fieldworks have successfully been carried out.

In 1985, the author proposed reforming the existing vertical type seawalls into the gentler front slope (1 to 5 or 6) seawalls. The laboratory test on the gentle slope seawall was made, and some experimental fieldworks were carried out. At this time, these new type gentler slope seawalls are successful.

## I. INTRODUCTION

On the 19th International Conference on Coastal Engineering, the author presented a paper titled " NEW TYPE BLOCKS FOR SEAWALL SLOPE PROTECTION " and proposed a gentle slope (1 to 3) seawall, covered with new type block named "Lotus-Uni" for measures against beach erosion. After the author's proposal, over one hundred works of the new type seawall have been carried out on various erosive sandy beaches in Japan, and most of these works have proved successful.

In 1985, the author proposed reforming the existing vertical type seawalls into the gentle slope (1 to 5 or 6 ) seawalls covered with Lotus- Uni. The reason for reforming is that, the existing vertical type seawalls have been disliked by inhabitants near the coast because of spray of seawater and environmental disruption.

## II. THE EXPERIMENTAL WORKS OF THE GENTLE SLOPE SEAWALL

The first experimental works of the gentle slope (1 to 3) seawall was carried out on Muroran Coast, Hokkaido Prefecture, facing the Pacific Ocean, in 1982.

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Dr.Eng.,Professor, School of Marine Scie. & Tech., Tokai Univ. Orido 3-20-1, Shimizu, Shizuoka Pref. 424 Japan.

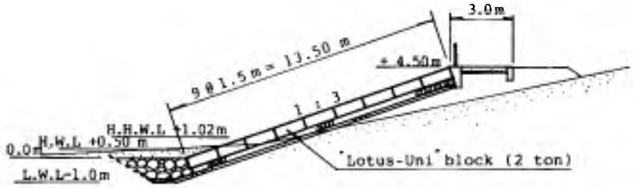



Fig.1. Cross section of the new type seawall on Muroran Coast.

Fig.1 shows the standard cross section of the new type gentle slope seawall covered with Lotus-Uni blocks. Nine blocks are arranged in each column, and no foundation nor shore protection works such as wave dissipation mounds were provided.

Photo 1. Experimental seawall immediately after the completion (1982).

As shown in Fig.1, the lowest blocks of the slope were set on the height of the mean water level, and there existed very narrow foreshore in front of the seawall. Uprush water mass with sands and gravels runs up on to the slope. Under the block facing, there lie a 50cm thick layer of cobbles and a 10cm layer of gravels. Part of the uprush flows into the holes of and the spaces between the blocks as shown in Photo 1. Thus the flow rate of backrush decreases, and wave reflection diminishes, the erosive beach tunning accumulative.

A later view of the beach is given in Photo 2. The shoreline has advanced remarkably, and the sand beach has grown extensively. Most part of the seawall is buried under the accumulated sand, only one block row being visible. The experimental seawall successfully change the erosive beach into a stable beach.

The result of this experimental works supported the author's confidence that a seawall against beach erosion snould have a rough and permeable facing, and its front slope should be gentle enough to diminish wave reflection.

Photo 2. A later view of the experimental seawall.

## III. GENTLER - SLOPE SEAWALL

When a gentle slope seawall is constructed on a narrow foreshore, the toe will be under the water. A gentler slope will yield a deeper toe, which may cause higher wave runup. Hence the determination of crown height as well as slope gentleness becomes an important problem.

### 3.1 Laboratory tests on wave runup on gentle slope

In general, wave runup on a gentle slope is lower than that on a steep slope. Fig.2 shows diagrams of the wave runup height based on laboratory measurements by Saville (1958), where $H_0$ is the offshore wave height and $H_0/L_0$ the offshore wave steepness. The laboratory test was conducted using periodic waves on smooth impermeable slopes. The slope of the model seabed was 1/10.

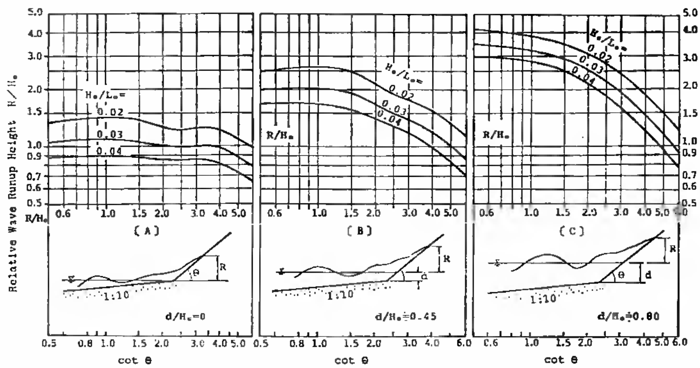



Fig.2 Wave runup height on smooth, impermeable slope faces on the seabed of 1/10 slope(Drawn after Saville,1958).

The diagram [A] is for cases of the relative toe depth $d/H_0=0$,[B] for $d/H_0=0.45$, and [C] for $d/H_0=0.80$.

The relative wave runup height $R/H_o$ in[A] is comparatively small and varied little with the structure slope (1/cot), where as $R/H_o$in[B] and [C] shows a considerable increase with the relative toe depth $d/H_o$ and with the slope. In the case of the structure slope of 1:5 or 1:6 ( $\cot\theta$ = 5 or 6), however, the runup height is considerably small and its variation with the toe depth is rather insignificant. then, the slope of 1:5 and 1:6 are very favorable to wave runup in comparison with the slope of 1:3 or 1:4. This is why the author regards gentler-slope seawalls as the optimum measure for shore protection.

Simultaneously with the proposal of the reforming the existing vertical type seawalls into the gentler-slope (1:5 or 1:6) seawalls,the author made some laboratory tests on the gentler-slope seawalls in the Tokai University.

The length of the two dimensions water tank was 52 m, water depth was 0.70m, slope of the model seabed was 1: 20, all model slopes were made as smooth and impermeable, and regular waves were used.

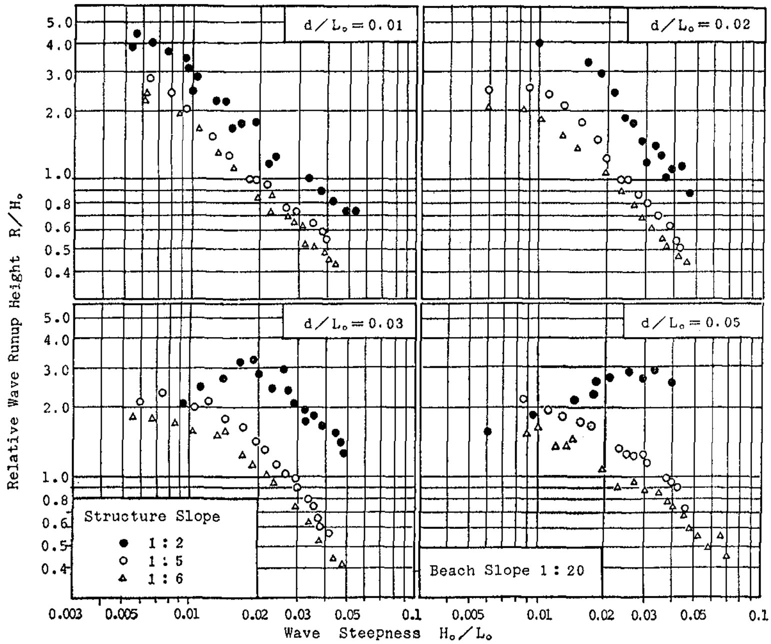



Fig.3 Wave runup height on smooth, impermeable slope faces on the seabed of 1:20 slope(by Toyoshima, 1985).

From the results of the laboratory test, as shown in Fig.3, it has become clear that,

(1) the wave runup height on 1:5 and 1:6 slope are considerably small in comparison with 1:2 slope.

(2) the depth at the toe of seawalls become deeper, gentler slope seawalls are advantageous on the runup heights, generally.

3.2 Experimental works of a reformed type seawall

A reformed type seawall with gentler slope, which toe was under the water, was experimentally constructed on Hongo Coast.

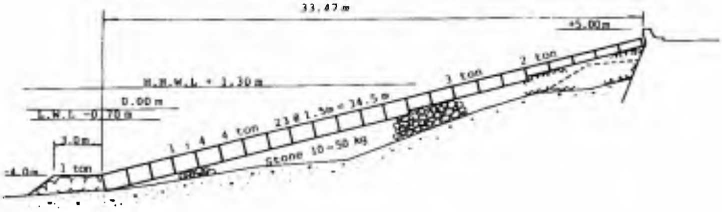
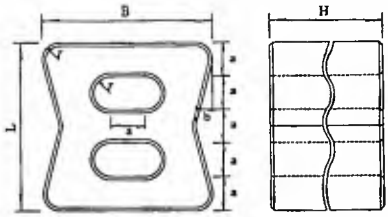



Fig.4 Reformed type experimental seawall on Hongo Coast.




| Model | B | L | H | Weight |
|---|---|---|---|---|
| 50 H | | | 50 cm | 2 ton |
| 75 H | 1.5 m | 1.5 m | 75 cm | 3 ton |
| 100 H | | | 100 cm | 4 ton |

Fig.5 Lotus-Uni block specification.

Fig.4 shows the standard cross section of the experimental works of reformed type seawall with gentler slope (1:4) on Hongo Coast. Three models of Lotus-Uni block were used as facing blocks without any special foundations or rubble stone works.

Photo 3. A former view of Hongo Coast (1977).

Photo 3 shows a former view of Hongo Coast in 1977 after the construction of the old seawall. A little sand beach were remaining.

Photo 4. Before the experimental works on Hongo Coast.

Photo 5. The experimental seawall under construction.

Photo 6. The experimental seawall completed.

Sand beach remaining in Photo 3 disappears in Photo 4 which was taken before the experimental works. In winter stormy weather, considerable amount of splash overtopped the seawall in spite of armour units placed in its front. Photo 5 shows the experimental seawall under construction. The depth at the toe of the slope was about 4 m.

The works was completed in August,1985,(Photo 6). Although this seawall has been attacked annually by severe winter waves, no collapse of the slopes or dispersion of the facing blocks has occured up to now.

## IV. GENTLER SLOPE SEAWALL ON KUROBE COAST

### 4.1 Construction of the experimental seawall

The first, real, reformed type, gentler (1:5) slope seawall, which toe was under the water, was experimentally constructed on Kurobe Coast, in fiscal 1986 and 1987. The location of Kurobe Coast is shown in Fig.6, together with Muroran and Hongo Coasts. The Kurobe Coast is one of the most eroded coast in Japan. Fig.7 and Fig.8 show the location and area of the experimental seawall works in Kurobe Coast. The wave recorder located about 500 m offshore from the coast, and 5 km to the experimental works site. The water depth of the wave recorder site is 15 m,and the wave recorder is set at -14m depth.

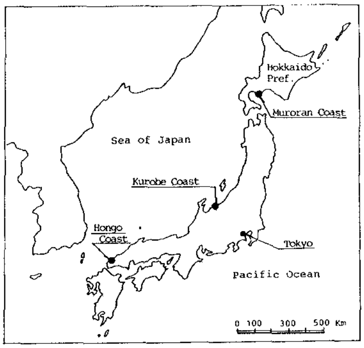



Fig.6 Location of Kurobe Coast and others.

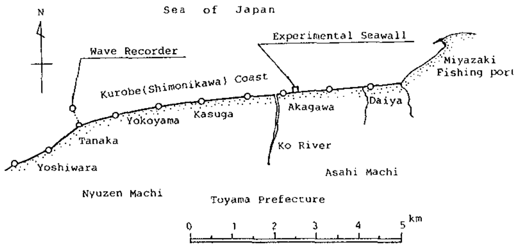



Fig.7 Location of the experimental seawall works.

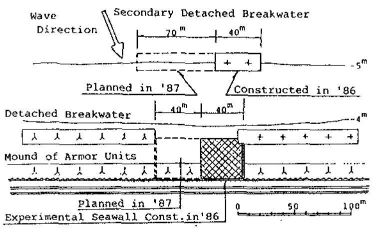



Fig.8 Areas of the experimental seawall works.

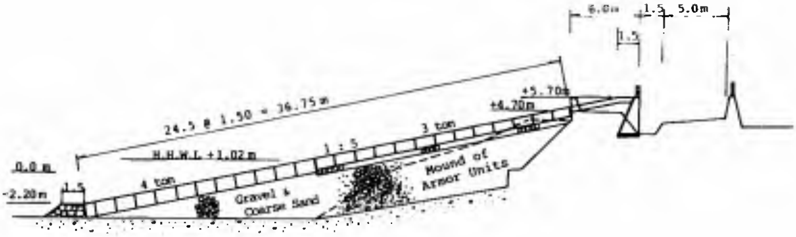



Fig.9 Standard cross section of the experimental seawall.

In fiscal 1986, a part of the experimental seawall and the secondary detached breakwater were constructed. The predominant direction of severe winter waves is NNW. The cross section of the experimental seawall is shown in Fig.9. The front slope is 1:5, and two models of Lotus-Uni, 4 ton and 3 ton, are used as the facing blocks without any special foundations. Removing the existing parapet wall, and reformation of the crown protection and retaining wall were carried out in fiscal 1987.

Photo 7 shows a latest view on the left-hand side of the experimental seawall construction site, and that is the same conditions before the experimental seawall works. There are vertical type seawalls, large mound of armour units for wave dissipation works and detached breakwaters. The weight of armour units for wave dissipation works and detached breakwaters are 8 ton and 20 ton respectively.

Photo 7. Left-hand side view of the experimental works.

First, as shown in Photo 8, the existing mound of armor units were removed.The existing seawalls are visible. Until the early 1960's, some narrow sandy beaches had been remaining in this area. However, immediately after the construction of this seawall, the beaches have vanished away. Then, large mound of armor units have been built, in order to protect the toe of seawalls from scouring and reduce the wave overtopping and splashing of sea water. However, these have been not enough to reduce the wave overtopping and splashing. And sometimes, the seawalls were damaged due to the leakage of the backfill sand.

Photo 8. First, mound of armour units were removed.

Photo 9. Filling of sand and gravel, which were diverted from the dredging of Miyazaki fishing port, located 4 km away from the site ( cf. Fig.7 ).

Photo 10. Setting the Lotus-Uniblock on the rubble stone. The lowest block were set at -3.3 m water depth.

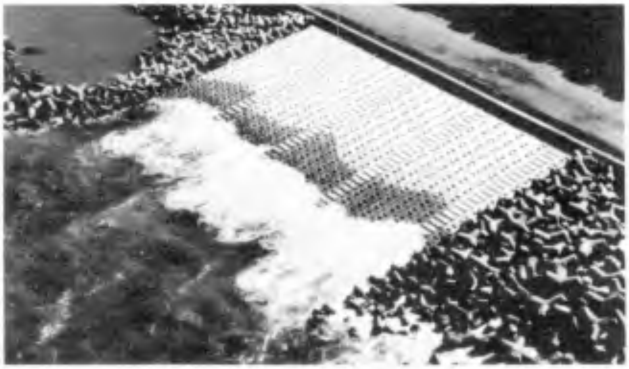


Photo 11. The works of the fiscal 1986 have completed in September 1986. The length of works is 40 m.

4.2 Observation of the wave runup on the seawall

After the completion of the experimental works, the first heavy wave struck the seawall in November 1986. On the 20th December 1986, pretty heavy waves attacked the Kurobe Coast, and overtopped the crown of the experimental seawall, as shown in Photo 12.

Photo 12. Heavy waves overtopped the crown of the experimental seawall, on the 20th December 1986.

The number of times of heavy wave attacks in the first winter season amounted to ten times. The wave runup heights on the experimental seawall were observed by eye measurement and video cameras in the field. Color lines were marked on the blocks for the observation of the wave runup height. These field observations have been done on each twenty minutes of the every O'clock in the day time on stormy weather days.

Table 1 shows the data of the waves which were obtained from the wave recorder, and of the calculated relative runup heights on the experimental seawall based on the field observation.

Table 1. Data of the waves and the calculated relative runup height on the experimental seawall based on the field observation.

| Date | Time | ① Nos. of Runp | ② Nos. of Waves | ③ Runup Count In | ④ $Ho$ ($H_{1/10}$) m | ⑤ $T$ ($T'_{1/10}$) s | ⑥ $Lo$ ($L_1'_{10}$) m | ⑦ Water Level +m | ⑧ Water Depth $d$m | ⑨ Runup Height $R$m | ⑩ $Ho/Lo$ | ⑪ $d/Lo$ | ⑫ $R/Ho$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| '86.11.26 | 10 | 120 | 245 | 25 | 2.28 | 7.4 | 85.4 | 0.38 | 3.58 | 3.09 | 0.027 | 0.042 | 1.36 |
| | 11 | 125 | 233 | 23 | 2.16 | 7.5 | 87.8 | 0.37 | 3.57 | 3.12 | 0.025 | 0.041 | 1.44 |
| | 12 | 127 | 231 | 23 | 2.12 | 7.8 | 94.9 | 0.36 | 3.56 | 2.97 | 0.022 | 0.038 | 1.40 |
| | 13 | 117 | 213 | 21 | 2.58 | 8.9 | 123.6 | 0.32 | 3.52 | 2.99 | 0.021 | 0.028 | 1.16 |
| | 14 | 108 | 223 | 22 | 2.25 | 8.6 | 115.4 | 0.31 | 3.51 | 3.49 | 0.020 | 0.030 | 1.55 |
| | 15 | 109 | 210 | 21 | 2.25 | 9.2 | 132.0 | 0.27 | 3.47 | 2.75 | 0.017 | 0.026 | 1.22 |
| 11.27 | 12 | 96 | 178 | 18 | 1.70 | 9.9 | 152.9 | 0.22 | 3.42 | 4.92 | 0.011 | 0.022 | 2.89 |
| | 14 | 89 | 199 | 20 | 1.32 | 9.5 | 140.8 | 0.15 | 3.35 | 4.68 | 0.009 | 0.024 | 3.55 |
| 12.15 | 10 | 145 | 213 | 21 | 2.18 | 7.2 | 80.9 | 0.25 | 3.45 | 2.79 | 0.027 | 0.043 | 1.28 |
| | 11 | 125 | 210 | 21 | 2.38 | 6.7 | 70.0 | 0.27 | 3.47 | 3.07 | 0.034 | 0.050 | 1.29 |
| | 12 | 131 | 218 | 22 | 2.73 | 6.9 | 74.3 | 0.30 | 3.50 | 3.48 | 0.037 | 0.047 | 1.27 |
| | 13 | 126 | 233 | 23 | 2.61 | 6.7 | 70.0 | 0.35 | 3.55 | 3.09 | 0.037 | 0.050 | 1.18 |
| | 14 | 126 | 233 | 23 | 2.45 | 6.5 | 65.9 | 0.38 | 3.58 | 3.02 | 0.037 | 0.054 | 1.23 |
| | 15 | 118 | 245 | 25 | 2.33 | 6.5 | 65.9 | 0.38 | 3.58 | 3.14 | 0.035 | 0.054 | 1.35 |
| 12.20 | 10 | 80 | 178 | 18 | 3.34 | 9.9 | 152.9 | 0.26 | 3.46 | 5.14 | 0.022 | 0.023 | 1.54 |
| | 11 | 92 | 159 | 16 | 3.66 | 9.2 | 132.0 | 0.26 | 3.46 | 5.29 | 0.028 | 0.026 | 1.44 |
| | 12 | 85 | 184 | 18 | 3.09 | 9.6 | 143.8 | 0.24 | 3.44 | 5.17 | 0.021 | 0.024 | 1.67 |
| | 13 | 95 | 164 | 16 | 3.45 | 10.2 | 162.3 | 0.23 | 3.43 | 5.12 | 0.021 | 0.021 | 1.48 |
| | 14 | 99 | 147 | 15 | 3.70 | 10.3 | 165.5 | 0.25 | 3.45 | 5.42 | 0.022 | 0.021 | 1.46 |
| | 15 | 89 | 144 | 14 | 3.22 | 10.3 | 165.5 | 0.28 | 3.48 | 4.93 | 0.019 | 0.021 | 1.53 |
| '87. 1.14 | 10 | 100 | 271 | 27 | 1.05 | 8.5 | 112.7 | 0.11 | 3.31 | 3.05 | 0.009 | 0.029 | 2.90 |
| | 11 | 98 | 253 | 25 | 1.36 | 8.8 | 120.8 | 0.11 | 3.31 | 3.18 | 0.011 | 0.028 | 2.34 |
| | 12 | 107 | 260 | 26 | 1.16 | 7.6 | 90.1 | 0.15 | 3.35 | 3.43 | 0.013 | 0.037 | 2.96 |
| | 13 | 107 | 251 | 25 | 1.14 | 9.1 | 129.2 | 0.18 | 3.38 | 3.03 | 0.009 | 0.026 | 2.66 |
| | 14 | 102 | 261 | 26 | 1.10 | 9.2 | 132.0 | 0.21 | 3.41 | 2.94 | 0.008 | 0.025 | 2.67 |
| | 15 | 100 | 233 | 23 | 1.29 | 9.4 | 137.8 | 0.24 | 3.44 | 3.14 | 0.009 | 0.025 | 2.43 |
| 2. 4 | 10 | 88 | 161 | 16 | 3.33 | 10.5 | 172.0 | 0.12 | 3.32 | 5.36 | 0.019 | 0.019 | 1.61 |
| | 11 | 82 | 164 | 16 | 3.06 | 9.6 | 143.8 | 0.07 | 3.27 | 5.46 | 0.021 | 0.023 | 1.78 |
| | 12 | 87 | 171 | 17 | 2.73 | 9.3 | 134.9 | 0.03 | 3.23 | 5.32 | 0.020 | 0.024 | 1.95 |
| | 13 | 87 | 161 | 16 | 2.59 | 9.4 | 137.8 | 0.03 | 3.23 | 5.42 | 0.019 | 0.023 | 2.09 |
| | 14 | 91 | 173 | 17 | 2.25 | 9.3 | 134.9 | 0.04 | 3.24 | 5.81 | 0.017 | 0.024 | 2.58 |
| | 15 | 80 | 191 | 19 | 2.46 | 9.5 | 140.8 | 0.03 | 3.23 | 5.21 | 0.017 | 0.023 | 2.12 |
| 2.26 | 10 | 89 | 217 | 22 | 2.68 | 8.3 | 107.5 | 0.13 | 3.33 | 4.35 | 0.025 | 0.031 | 1.62 |
| | 11 | 105 | 212 | 21 | 2.79 | 8.7 | 118.1 | 0.19 | 3.39 | 4.45 | 0.024 | 0.029 | 1.59 |
| | 12 | 93 | 243 | 24 | 2.40 | 9.0 | 126.4 | 0.23 | 3.43 | 4.45 | 0.019 | 0.027 | 1.85 |
| | 13 | 89 | 244 | 24 | 2.36 | 7.9 | 97.4 | 0.28 | 3.48 | 4.26 | 0.024 | 0.036 | 1.80 |
| | 14 | 90 | 196 | 20 | 2.58 | 9.8 | 149.8 | 0.31 | 3.51 | 4.50 | 0.017 | 0.023 | 1.74 |
| | 15 | 89 | 199 | 20 | 3.00 | 10.7 | 178.6 | 0.32 | 3.52 | 4.73 | 0.017 | 0.020 | 1.58 |
| 2.27 | 10 | 77 | 141 | 14 | 2.82 | 12.5 | 243.8 | 0.12 | 3.32 | 5.37 | 0.012 | 0.014 | 1.90 |
| | 11 | 75 | 145 | 15 | 3.03 | 12.9 | 259.6 | 0.16 | 3.36 | 5.12 | 0.012 | 0.013 | 1.69 |
| | 12 | 68 | 153 | 15 | 2.58 | 13.1 | 267.7 | 0.21 | 3.41 | 4.85 | 0.010 | 0.013 | 1.88 |
| | 13 | 82 | 159 | 16 | 2.59 | 12.8 | 255.6 | 0.28 | 3.48 | 4.73 | 0.010 | 0.014 | 1.83 |
| | 14 | 72 | 194 | 19 | 2.29 | 12.5 | 243.8 | 0.34 | 3.54 | 4.61 | 0.009 | 0.015 | 2.01 |
| | 15 | 83 | 154 | 15 | 2.65 | 11.9 | 220.9 | 0.35 | 3.55 | 4.32 | 0.012 | 0.016 | 1.63 |

Because of the great differences between number of recorded waves and observed runup waves to the experimental seawall, the author used the one-tenth highest wave and the same numbers of the highest wave runup, in the arrangement. For example, in the case of

the date the 20th December 1986,
time 14 o'clock

in the Table 1,

(1) the number of the observed runup waves to the experimental seawall in twenty minutes is 99.
(2) the number of the waves recorded in the wave recorder in twenty minutes is 147.
(3) calculated number of the one-tenth highest wave is 15. and the same number of highest wave runup are adopted.
(4) one-tenth highest wave height is 3.70 m.
(5) one-tenth highest wave period is 10.3 s.
(6) calculated offshore wave length $L_o$ is 165.5 m.
(7) sea water level at that time is +0.25 m.
(8) water depth at the toe of the seawall is 3.45 m.
(9) the mean value of the highest 15 waves runup height, adopted in (3), measured from the sea water level is 5.42 m.
(10) wave steepness $H_o/L_o$ (4)/(6)=3.70/165.5 = 0.022.
(11) relative water depth $d/L_o$(8)/(6)= 3.45/165.5 = 0.021.
(12) relative wave runup height $R/H_o$ (9)/(4) = 1.46

The wave runup height is

5.42 m + 0.25 m = + 5.67 m ≒ + 5.70 m ( Crown height)

Naturally, a number of runup waves overtopped the crown of the experimental seawalls, as shown in Photo 12.

4.3 Comparing the field observation data with laboratory test results

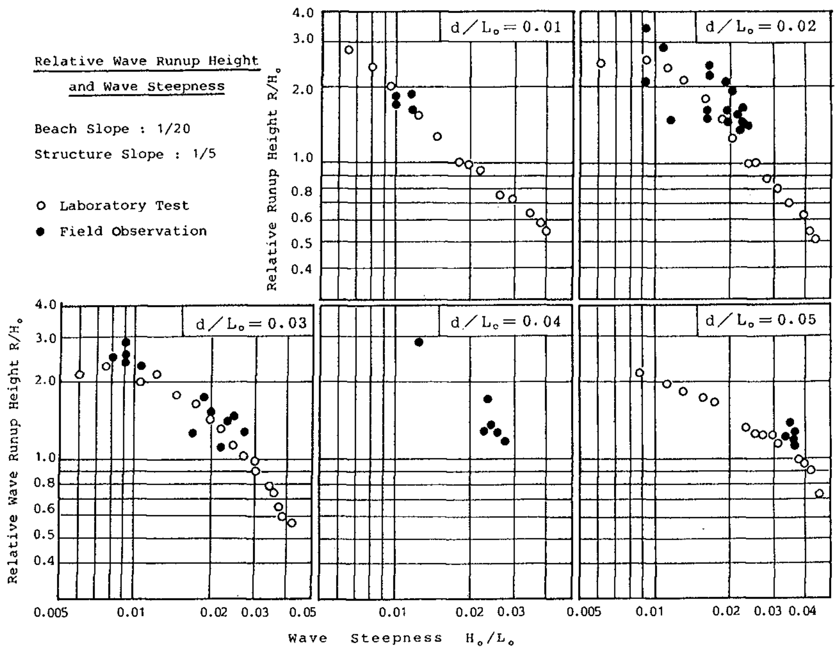



Fig.10. Comparison between the laboratory test and the field observation on the wave runup height on gentle slope seawalls.

The data of the field observation are ploted in Fig.10, together with the data of the laboratory test. Open circles are laboratory test and solid dots are field observation. At a grance, both of these data show a good agreement. The slope of the seawalls in the field are covered with armour units, but in the laboratory test all slope of model are smooth and impermeable. The waves in the laboratory test were regular waves. The wave recorder is 5 km away from the site of works, the runup waves are not the same waves as recorded by the wave recorder.

Although,there are many problems in these data and their caluculation processes, the author considers that these results on the gentle slope 1:5 seawalls are very useful for designing of the shore protection in future.

4.4 The works of fiscal 1987 was completed

Pnoto 13. The works of fiscal 1987 was completed. The left half are of fiscal 1986.

Photo 14. Heavy waves attacked the Kurobe Coast, and some of them overtopped the experimental seawalls.

On 6th November 1987, heavy winter waves attacked the Kurobe Coast, and some of them overtopped the experi-mental seawalls. However, the spray of sea water on the gentle slope seawalls were excessively small in comparison with that of existing vertical type seawalls with large mound of armour units.

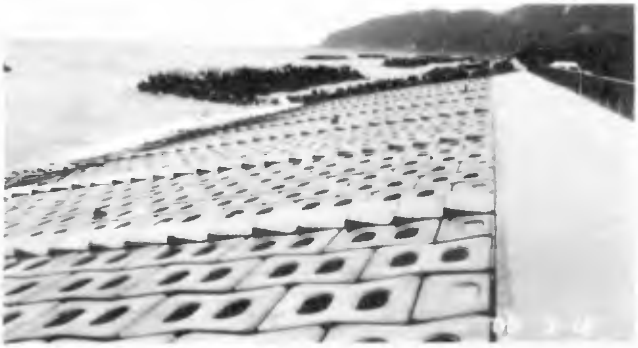


Photo 15. The latest view of the experimental seawalls.

After the construction of the experimental works, one or two winter season are over, but there has not been any trouble, damage or collapse, on the body, slope, covering blocks, foot and toe of the experimental works. At this time, these new type gentler slope seawalls are successful.

## V. CONCLUSION

Many of existing vertical type seawalls have lost their foreshore, and wave dissipation works are not effective enough to prevent the overtopping of the splash and sea water mass. On the basis of the successful results and experiences obtained through the experimental works, the author proposed to reform existing vertical type seawalls to gentler slope seawalls with armour unit facing.

In conclusion, in order to maintain better coastal environment, structures on an erosive coast are desired to satisfy the following conditions:

(1) the wave reflection from the front slope should be minimized,
(2) scouring at the structure toe should be prevented as well as erosion of the foreshore,
(3) the whole structure should not collapse even if partial breakdown took place,
(4) the crown of the structures should not be too high,
(5) repairs and reinforcements should be easy, and
(6) the structure should be rather simple and not too costly.

In this view, the gentler slope seawall with rough and permeable front slope is one of the most relevant countermeasures against the beach erosion.

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