CHAPTER 4

REGULAR WAVE MODEL

4.1 Data Collection

In order to develop the mathematical model, the reliable data obtained from the experiments is the most important and essential part. For regular breaking wave model, the computation of energy dissipation rate is based on the empirical formula due to its complication. Hence the wide range and reliable of data obtained from the experiments are important to the accuracy of the prediction of the wave height. In this study, the 14 sources of published laboratory results contained 508 cases have been used to calibrate and to verify the regular breaking wave model to ensure the precision of the predicted wave height.

Table 4.1 Summary of collected experimental data

No.	Sources	No. of cases	Bed Condition	Apparatus
1	Cox and Kobayashi (1997)	1	Plane beach	Small-scale
2	Hansen and Svendsen (1979)	15	Plane beach	Small-scale
3	Hansen and Svendsen (1984)	1	Plane beach	Small-scale
4.1	Horikawa and Kuo (1966) slope= 0	101	Plane and stepped beach	Small-scale
4.2	Horikawa and Kuo (1966) slope=1/80-1/20	112	Plane and stepped beach	Small-scale
5	Kajima et al. (1983)	79	Sandy beach	Large-scale
6	Kraus and Smith (1994)	57	Sandy beach	Large-scale
7	Nadaoka et al. (1982)	2	Plane beach	Small-scale
8	Nagayama (1983)	12	Plane, stepped, barred beach	Small-scale
9	Okayasu et al. (1988)	10	Plane beach	Small-scale
10	Sato et al. (1988)	3	Plane beach	Small-scale
11	Sato et al. (1989)	2	Plane beach	Small-scale
12	Shibayama and Horikawa (1986)	10	Sandy beach	Small-scale
13	Smith and Kraus (1990)	101	Plane and barred beach	Small-scale
14	Ting and Kirby (1994)	2	Plane beach	Small-scale
Total		508		

4.2 Existing Regular Wave Models

4.2.1 Bore concept

Le Mehaute (1962) made an analytical investigation to describe the physical behavior of the wave transformation due to a spilling breaker is similar to a bore (Stoker 1957). The average rate of energy dissipation can be calculated as

$$D_B = \frac{1}{4}\rho g \frac{(h_2 - h_1)^3}{h_1 h_2} Q \tag{4.1}$$

where ρ is water density, g is the acceleration due to gravity, h_1 is the lower conjugate depth, h_2 is the higher conjugate depth (see Fig. 4.1), Q is the volume discharge per unit area across the bore which is equal to $(ch/L) = (h/T)$ (Hwang and Divoky 1970) and T is the wave period. Substitute this relation into Eq. (4.1) and consider that $h_2 - h_1 \approx H$ then equation can be rewritten as

$$D_B = \frac{1}{4}\frac{\rho g h H^3}{T h_1 h_2} \tag{4.2}$$

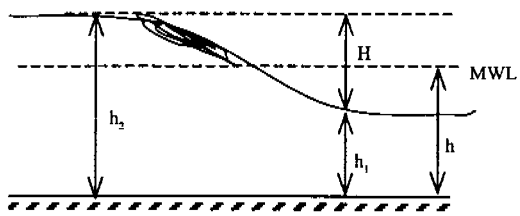

Fig. 4.1 Definition sketch of a breaking wave profile

A formula was developed by Battjes and Janssen (1978), hereafter referred to as BJ formula, idea to predict the dissipation of energy in random waves breaking on a beach based on bore concept. By reducing the dependence on the depth by assuming that $h_1 h_2 = h^2$ and $H/h = 1$. Substitute this relation into Eq. (4.2) then it can be rewritten as

$$D_B = K_1 \frac{\rho g H^2}{4T} \tag{4.3}$$

where K_1 is the empirical coefficient introduced to account for the difference between a breaking wave and hydraulic jump.

Thornton and Guza (1983), hereafter referred to as TG formula, presented a refinement of BJ's formula by assuming that $h_1 h_2 = h^2$ in Eq. (4.2). Therefore the general form of the rate of energy dissipation can be expressed as

$$D_B = K_2 \frac{\rho g H^3}{4Th} \tag{4.4}$$

where K_2 is the empirical coefficient.

Stive (1984), hereafter referred to as Stive, studied the energy dissipation in wave breaking on gentle sloping beach. In order to model the turbulence in the surf zone and estimate the energy dissipation based on bore concept. Stive's measurements indicated that in the inner region, the model was underestimated the energy dissipation by 30-50% for breaking wave with the same height. To overcome this, Stive (1984) proposed the dissipation factor A_E as

$$A_E \approx 2 \tanh 5\xi_o \tag{4.5}$$

where the deep water similarity parameter, $\xi_o = m / \sqrt{(H_o / L_o)}$, m is the beach slope, H_o is the deep water wave height and L_o is the deep water wave length.

After combine the dissipation factor A_E with Eq. (4.4) then the general form of energy dissipation rate becomes

$$D_B = K_3 A_E \frac{\rho g}{4Th} H^3 \tag{4.6}$$

where K_3 is the empirical coefficient.

Deigaard et al. (1991), hereafter referred to as DJF, developed the formula to express the rate of energy dissipation of a broken wave. When the waves break in the surf zone, wave height and wave energy decrease toward the shoreline due to the strong energy dissipation. The energy dissipation is expressed through the energy loss in a bore. By substituting $h_1 = h - (H/2)$ and $h_2 = h + (H/2)$ into Eq. (4.2) then the rate of energy dissipation can be expressed as

$$D_B = K_4 \frac{\rho g h H^3}{T(4h^2 - H^2)} \tag{4.7}$$

where K_4 is the empirical coefficient.

Karambas and Koutitas (1992), hereafter referred to as KK, modified Stive's model by including the wave height stabilization which can be associated to the wave re-forming process. By applying the stable wave concept which was proposed by Dally et al. (1985) to Stive's model (1984), the modification of energy dissipation rate can be expressed as

$$D_B = K_5 A_E \frac{\rho g}{4T} \left[\frac{H^3}{h} - \Gamma^3 h_b^2 \right] \tag{4.8}$$

where K_5 is the empirical coefficient, Γ is the stable wave coefficient which equal to 0.35 when $m \geq 1/30$ and equal to 0.30 when $m < 1/30$ and h_b is the breaking depth.

4.2.2 Stable energy concept

This concept is developed based on the propagation of breaking wave on a horizontal bottom (see Fig. 4.2). When a breaking wave enters a zone of horizontal bottom, the breaking will continue, and the wave height will decrease, until a stable wave height is attained. Therefore, Dally et al. (1985) assumed that the energy dissipation rate is proportional to the difference between the local energy flux and the stable energy flux, divided by the local water depth as

$$D_B = \frac{K_d}{h} \left[E c_g - (E c_g)_s \right] \tag{4.9}$$

where K_d is the decay coefficient, and subscript s is the variable at stable wave, $E = \rho g H^2/8$, $E_s = \rho g H_s^{\ 2}/8$, $H_s = \Gamma h$ is the stable wave height, Γ is a dimensionless coefficient and estimated between 0.35-0.40 (Dally et al. 1985). After substituting all variables, Eq. (4.9) can be written as

$$D_B = K_d \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma h)^2\right] \tag{4.10}$$

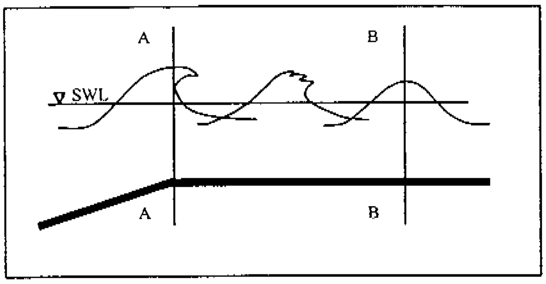

Fig. 4.2 Shelf beach idealization of the surf zone

The advantage of the stable energy concept is that it is able to reproduce the pause or stop breaking in the wave breaking process at a finite wave height on a horizontal bed or in the recovery zone while the bore formula gives a continuous dissipation due to wave breaking.

Dally et al. (1985), hereafter referred to as DDD formula, determined the best values for Γ and the wave decay K_d by calibrating the formula with the laboratory data of Horikawa and Kuo (1966). The best fit values for the two coefficients vary with beach slope especially as the beach becomes steeper. Finally, the best fit occurs at $\Gamma = 0.4$ and $K_d = 0.15$. Substituting $\Gamma = 0.4$ into Eq. (4.10), the energy dissipation rate can be rewritten as

$$D_B = K_6 \frac{c_g \rho g}{8h}\left[H^2 - (0.4h)^2\right] \tag{4.11}$$

where K_6 is the empirical coefficient.

Rakha and Kamphuis (1995), hereafter referred to as RK formula, developed the wave formula to be accounted for the wave reflection. They studied the effect of the wave steepness H/L and included into the Γ equation. After calibration, the equation can be written as

$$\Gamma_{RK} = 0.277 + 2.46\left(\frac{H}{L}\right) \tag{4.12}$$

where H/L is the wave steepness. Substituting Γ from Eq. (4.12) into Eq. (4.10), the energy dissipation rate can be expressed as

$$D_B = K_7 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma_{RK} h)^2\right] \quad (4.13)$$

where K_7 is the empirical coefficient.

Based on the analysis of experimental data of Kajima et al. (1983), Rattanapitikon and Shibayama (1996), hereafter referred to as RS formula, modified the DDD formula and proposed the determination function of Γ from the correlation between the measured Γ and the computed Γ. The measured Γ can be calculated from

$$\Gamma = \frac{1}{h}\sqrt{H^2 - \frac{\partial(Ec_g)}{\partial x}\frac{8h}{0.15c\rho g}} \quad (4.14)$$

An attempt is made to correlate the parameter Γ with other wave parameters. The result shown that the correlation between Γ and $h/\sqrt{LH}$ appeared to be the best. The formula for the stable wave factor Γ can be expressed as

$$\Gamma_{RS} = \exp\left[-0.36 - 1.25\frac{h}{\sqrt{LH}}\right] \quad (4.15)$$

Finally, the dissipation rate becomes

$$D_B = K_8 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma_{RS} h)^2\right] \quad (4.16)$$

where K_8 is the empirical coefficient.

4.3 Model Calibration

A total of 8 models have been studied as summarized in Table 4.2. These previous models had been calibrated by using the published experimental data in Table 4.1. The root mean square relative error (ER) which have been used to calibrate the models can be expressed as

$$ER = 100\sqrt{\sum_{i=1}^{tn}(H_{ci} - H_{mi})^2 / \sum_{i=1}^{tn} H_{mi}^2} \quad (4.17)$$

where i is the wave height number, H_{ci} is the computed wave height of number i, H_{mi} is the measured wave height of number i, and tn is the total number of measured wave height. The smaller value of ER represents the better wave height prediction.

A calibration of dissipation models conducted by varying the empirical coefficients in each dissipation formula until the minimum error between the measured and computed wave height is obtained. The calibrations are also divided into 4 different cases due to beach conditions and 2 wave flume scales, which are plane beach, barred beach, stepped beach, sandy beach, small-scale wave flume and large-scale wave flume experiment. The calibration results are presented in Table 4.4-4.10.

Table 4.2 List of the existing dissipation models

No.	Model	Concept	Formula
1	Battjes and Janssen (1978)	Bore concept	$D_B = K_1 \frac{\rho g h H^2}{4T}$
2	Thornton and Guza (1983)		$D_B = K_2 \frac{\rho g H^3}{4Th}$
3	Stive (1984)		$D_B = K_3 A_E \frac{\rho g}{4Th} H^3$ $A_E = 2 tanh 5\xi_o$
4	Deigaard et al. (1991)		$D_B = K_4 \frac{\rho g h H^3}{T(4h^2 - H^2)}$
5	Karambas and Koutitas (1992)		$D_B = K_5 A_E \frac{\rho g}{4T}\left[\frac{H^3}{h} - \Gamma^3 h_b^2\right]$ $\Gamma = 0.30$ $if\ m < 1/30$ $= 0.35$ $if\ m \geq 1/30$
6	Dally et al. (1985)	Stable energy concept	$D_B = K_6 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma h)^2\right]$ $\Gamma = 0.4$
7	Rakha and Kamphuis (1995)		$D_B = K_7 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma h)^2\right]$ $\Gamma = 0.277 + 2.46(H/L)$
8	Rattanapitikon and Shibayama (1996)		$D_B = K_8 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma h)^2\right]$ $\Gamma = exp(-0.36 - 1.25 \frac{h}{\sqrt{LH}})$

4.4 Model Comparison

After calibrated the 8 existing dissipation models in Table 4.2 with the published experimental results in Table 4.1, the accuracy of each model has been examined and presented in Table 4.4-4.10 depends on the beach conditions. The error of each model has been compared to determine the model, which gives the most accurate wave height prediction. The comparison of the accuracy of each model from bore concept and stable energy concept is summarized in Table 4.3. For bore concept, TG model gives the minimum error for all cases and also gives the most accurate predicted wave height for plane beach and small scale wave flume. In case of barred beach, sandy beach and large-scale wave flume, the model that gives the minimum error is KK model. For stepped beach, it is found that DJF model has the minimum error. The error of each model of bore concept ranges between 17.10%-20.54%. However, every model gives the same range of accuracy.

For stable energy concept, it can be noticed that RS model gives the minimum error in every case and the error ranges from 11.84% to 17.09%. These results can confirm the accuracy and the validity of RS model. In order to improve the dissipation model, further development from the model, which gives the minimum error from the comparison results, has been made. In this study, RS model has been selected due to the results of the comparison as summarized in Table 4.3. There is a tendency to develop RS model by improving the equation of the stable wave function. Even though the single value of the stable wave coefficient is preferable due to its convenient, but it is not suitable for a variety of beach conditions. Therefore, the stable wave function has been proposed in order to improve the error from using only single value.

Table 4.3 Summary of the models that give the minimum error of each case from the comparison results

Table No.	Experimental conditions	Minimum error (%*ER*)	
		Bore concept	**Stable energy concept**
4.4	all cases	TG (20.54%)	RS (15.85%)
	Beach condition		
4.5	plane beach	TG (17.48%)	RS (13.84%)
4.6	barred beach	KK (18.41%)	RS (14.86%)
4.7	stepped beach	DJF (17.10%)	RS (11.84%)
4.8	sandy beach	KK (20.28%)	RS (17.05%)
	wave flume scale		
4.9	small scale	TG (19.17%)	RS (15.40%)
4.10	large scale	KK (20.35%)	RS (17.09%)

4.5 Model Development

Since Rattanapitikon and Shibayama (1996) developed the stable wave function from the correlation between $h/\sqrt{LH}$ and the measured Γ (see Fig. 4.3). After found that this relation appeared to be the best compared with other possibility dimensionless parameters such as h/L_o and h/L. The equation of the measured Γ can be expressed as

$$\Gamma = \frac{1}{h}\sqrt{H^2 - \frac{\partial(EC_g)}{\partial x}\frac{8h}{0.15c\rho g}} \tag{4.18}$$

After calibration by using the laboratory data of Kajima et al. (1983), the stable wave coefficient of RS model can be written as

$$\Gamma_{RS} = \exp(-0.36 - 1.25\frac{h}{\sqrt{LH}}) \tag{4.19}$$

Therefore, there is a tendency to develop the model in order to improve the accuracy if other physical parameter such as a local beach slope has been accumulated. To incorporate the effect of the local beach slope to RS model, the equation can be modified as

$$\Gamma_p = \exp\left[a_1 m^p + a_2\left(\frac{h}{\sqrt{LH}}\right)^q + a_3\right] \quad (4.20)$$

where m is the local beach slope.

The calibration has been made by using the measured Γ (determined from Eq. 4.18) from the experimental data in Table 4.1. After calibration, the following formula fits well with the measured Γ.

$$\Gamma_p = \exp\left[-22.22m^2 - 1.25\frac{h}{\sqrt{LH}} - 0.31\right] \quad (4.21)$$

Finally the developed stable wave function of the present study (hereafter referred to as PS) can be obtained and it can be expressed as

$$D_B = K_9 \frac{c_g \rho g}{8h}\left[H^2 - (\Gamma_p h)^2\right] \quad (4.22)$$

where $\Gamma_p = \exp\left[-22.22m^2 - 1.25\frac{h}{\sqrt{LH}} - 0.31\right]$ and K_9 is the empirical coefficient. After calibration with the published experimental data in Table 4.1, coefficient K_9 is found to be 0.17.

To check the accuracy of the present model, the present formula has been calibrated with the laboratory data in Table 4.1 in order to determine the empirical constant, K_9, until the minimum error is obtained. Then compared this error to the errors of 8 existing dissipation models. It is found that the present model can improve the accuracy and it gives a minimum error equal to 14.67% and occurred at $K_9 = 0.17$ (see Table 4.4). The calibrations are also classified into 4 different beach conditions and 2 different size of wave flumes, which are plane beach, barred beach, stepped beach, sandy beach, small-scale wave flume and large-scale wave flume. The results are present in Table 4.5-4.10 and it is revealed that the present model gives the minimum error for most cases except for the stepped beach that RS model gives the minimum error. The summary of the optimal empirical coefficient $K_1 - K_9$ of each case is summarized in Table 4.11.

Fig. 4.4 shows the correlation between Γ and the parameter $h/\sqrt{LH}$ including the present model with the effect of the local slope 0-1/20 by using the experimental data of Kajima et al. (1983). Fig. 4.5 shows the comparison between the measured and computed wave height of the present model by using data from Table 4.1. Fig. 4.6 shows the examples of the computed wave heights compared with laboratory data of Okayasu (1988), Shibayama and Horikawa (1986), Kajima et al. (1983). The examples of the computed wave heights compared with laboratory data from various sources are presented in Appendix A.

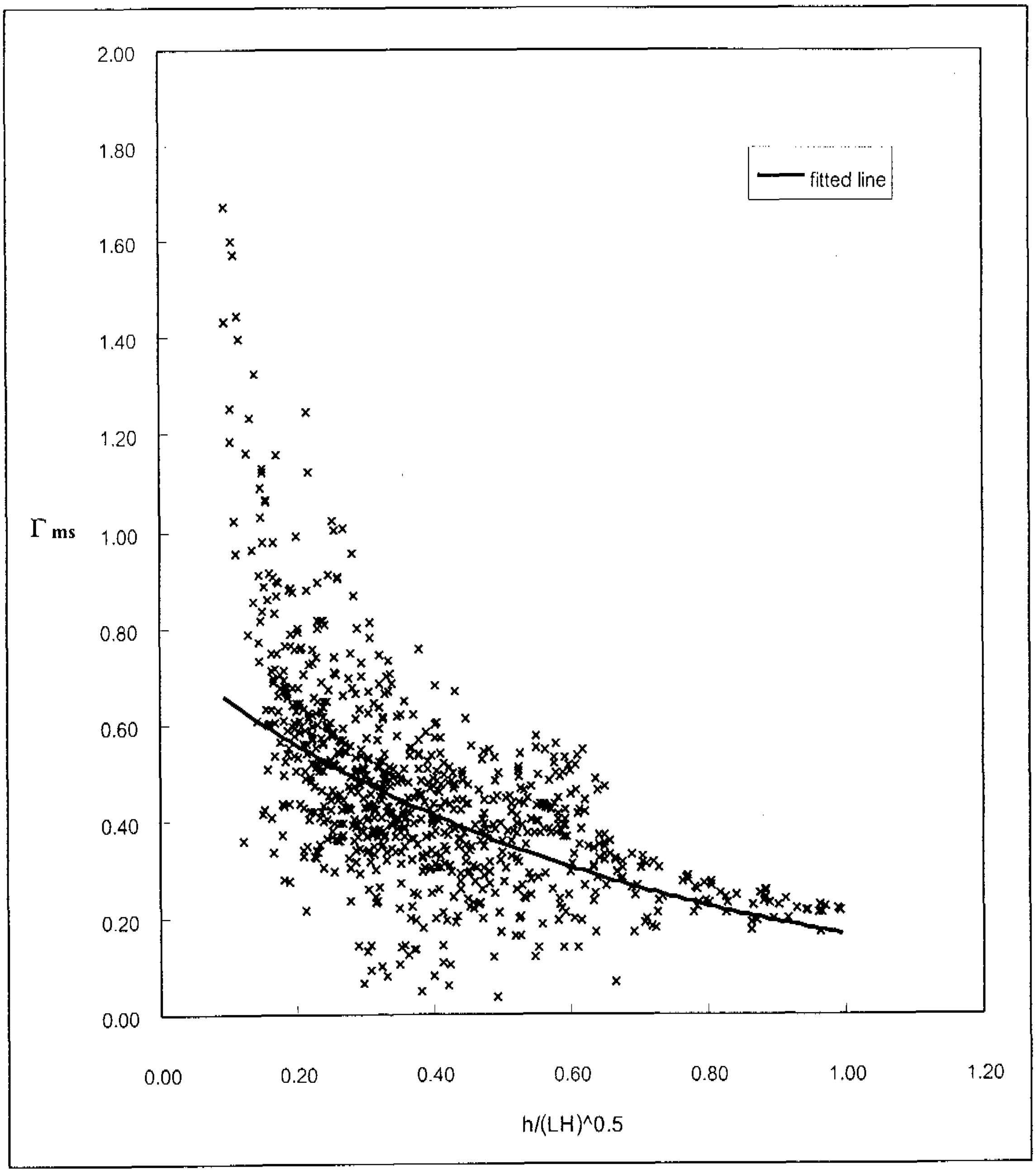

Fig. 4.3 The correlation between the measured Γ and the parameter $h/\sqrt{LH}$ by using the laboratory data of Kajima et al. (1983)

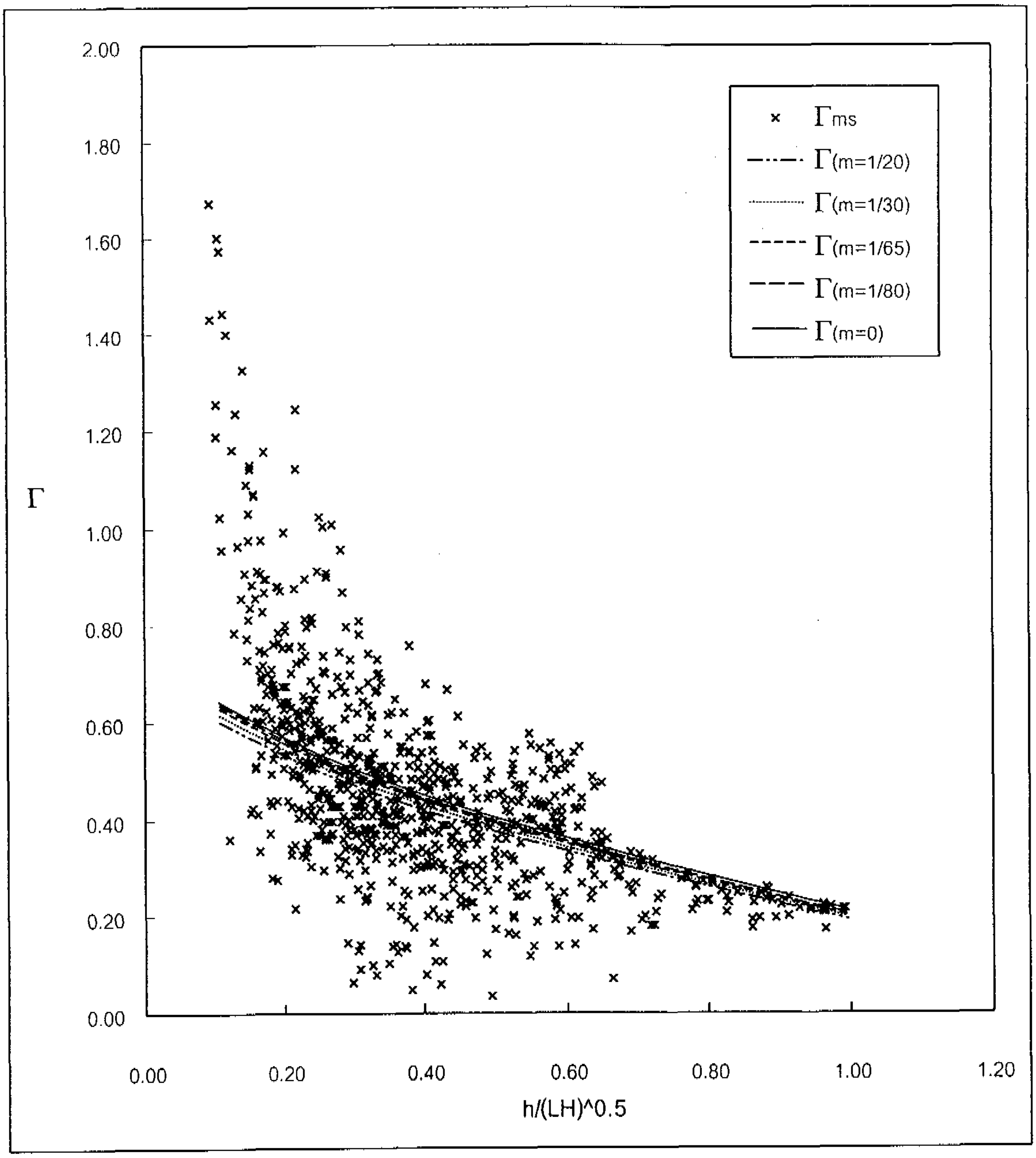

Fig. 4.4 The correlation between Γ and parameter $h/\sqrt{LH}$ including the present model with the local slope 0-1/20 by using the laboratory data of Kajima et al. (1983)

Table 4.4 The root mean square relative error of each model for all cases

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
1	1	38.32	28.37	33.06	24.78	35.61	25.77	21.46	23.63	20.85
2	15	39.08	24.72	19.69	24.96	14.46	11.97	11.76	11.08	11.78
3	1	26.34	7.27	3.02	9.95	9.89	11.08	10.50	9.98	8.06
4.1	101	19.07	14.39	51.95	14.96	51.95	14.04	14.01	11.59	12.54
4.2	112	37.24	25.65	15.54	21.47	15.27	16.20	15.55	18.05	16.47
5	79	51.70	26.40	22.51	22.91	18.96	20.62	21.10	16.30	16.01
6	57	32.12	22.43	20.89	24.28	25.86	22.30	22.96	19.12	17.88
7	2	36.47	20.04	18.07	16.91	20.88	7.18	7.24	9.47	9.61
8	12	21.32	12.74	29.17	10.80	26.23	10.15	11.19	8.60	9.27
9	10	45.52	21.51	11.96	20.89	16.12	12.97	13.01	12.08	11.80
10	3	22.61	10.49	11.86	11.07	19.18	6.48	6.97	8.38	8.28
11	2	11.31	14.96	11.83	12.42	18.97	20.76	20.44	22.21	19.48
12	10	43.79	22.11	19.58	26.47	17.80	18.34	17.84	16.89	16.18
13	101	39.91	24.44	27.04	36.12	26.16	23.68	23.40	20.10	15.33
14	2	46.33	31.25	33.43	28.13	33.46	33.18	31.18	26.12	24.52
AVG. (total 508 cases)		**32.51**	**20.54**	**26.29**	**21.06**	**25.66**	**17.65**	**17.47**	**15.85**	**14.67**

Table 4.5 The root mean square relative error of each model for plane beach

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
1	1	32.10	25.56	36.83	24.14	47.08	24.42	21.46	22.73	20.15
2	15	44.92	29.35	26.72	26.69	20.06	13.39	11.76	12.24	13.51
3	1	34.95	14.76	6.19	12.73	15.23	8.26	10.50	7.40	5.56
4.1	101	19.12	15.54	51.95	15.72	51.95	14.37	14.01	12.01	13.17
4.2	72	30.98	21.92	13.40	20.20	11.45	15.35	16.07	18.07	16.19
7	2	39.69	21.18	21.34	17.24	23.77	7.31	7.24	8.29	8.37
8	1	39.57	20.64	6.15	17.46	10.39	8.52	6.02	6.54	6.36
9	10	53.97	27.67	11.15	22.95	18.09	13.26	13.01	11.91	11.77
10	3	31.49	13.02	15.91	11.96	22.52	6.37	6.97	6.98	7.00
11	2	8.46	11.25	14.41	12.01	22.09	17.97	20.44	19.24	17.86
13	29	50.47	24.96	39.31	36.24	37.95	21.33	15.57	14.50	13.51
14	2	42.59	29.57	35.42	27.55	39.45	32.27	31.18	25.51	23.95
AVG. (total 239 cases)		**26.07**	**17.48**	**32.67**	**17.88**	**32.45**	**15.27**	**14.66**	**13.84**	**13.59**

Table 4.6 The root mean square relative error of each model for barred beach

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
8	5	22.39	14.37	15.82	11.15	12.14	11.89	11.03	13.75	11.04
13	72	38.16	24.45	23.07	35.73	21.47	18.24	18.53	15.55	12.76
AVG. (total 77 cases)		**37.38**	**23.12**	**21.45**	**29.12**	**18.41**	**16.45**	**16.66**	**14.86**	**11.99**

Table 4.7 The root mean square relative error of each model for stepped beach

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
4.2	40	29.71	18.64	19.71	18.73	18.30	12.85	13.14	12.52	12.93
8	6	37.11	14.04	34.98	9.86	38.67	12.99	15.50	10.96	12.78
AVG. (total 46 cases)		**27.74**	**17.73**	**19.81**	**17.10**	**20.18**	**12.60**	**12.69**	**11.84**	**12.31**

Table 4.8 The root mean square relative error of each model for sandy beach

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
5	79	47.30	25.12	22.43	24.71	18.88	20.06	21.06	16.30	16.16
6	57	38.94	23.63	21.87	23.60	26.01	21.87	22.92	19.12	18.00
12	10	27.23	16.57	18.13	25.59	17.73	17.15	17.82	16.89	16.65
AVG. (total 146 cases)		**35.62**	**22.34**	**20.68**	**22.02**	**20.28**	**19.10**	**19.37**	**17.05**	**16.44**

Table 4.9 The root mean square relative error of each model for small scale project

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
1	1	35.28	27.33	33.06	24.14	40.98	25.77	21.46	23.63	20.85
2	15	41.90	26.16	30.46	26.69	24.22	11.97	11.76	11.08	12.17
3	1	30.60	9.67	3.02	12.73	8.16	11.08	10.50	9.98	8.06
4.1	101	18.88	14.63	51.95	15.72	51.95	14.04	14.01	11.59	12.54
4.2	112	36.03	24.35	15.54	20.40	15.44	16.20	15.55	18.05	16.47
7	2	37.83	20.15	18.07	17.24	20.01	7.18	7.24	9.47	9.61
8	12	19.91	12.17	29.17	10.98	26.48	10.15	11.19	8.60	9.27
9	10	49.61	23.40	11.96	22.95	15.75	12.97	13.01	12.08	11.80
10	3	26.89	10.86	11.86	11.96	18.13	6.48	6.97	8.38	8.28
11	2	8.14	13.34	11.83	12.01	18.10	20.76	20.44	22.21	19.48
12	10	47.18	23.59	19.58	28.09	18.02	18.34	17.84	16.89	16.18
13	101	40.73	24.88	27.04	35.82	25.82	23.68	23.40	20.10	15.33
14	2	44.55	30.66	33.43	27.55	36.92	33.18	31.18	26.12	24.52
AVG. (total 372 cases)		**30.03**	**19.17**	**28.58**	**20.49**	**27.92**	**17.06**	**16.71**	**15.40**	**14.00**

Table 4.10 The root mean square relative error of each model for large scale project

Source No.	No. of cases	ERROR								
		Bore concept					Stable energy concept			
		BJ	TG	Stive	DJF	KK	DDD	RK	RS	PS
5	79	47.48	25.09	22.38	24.57	18.88	20.62	21.10	16.30	16.16
6	57	37.94	23.45	21.55	23.61	26.01	22.30	22.96	19.12	18.00
AVG. (total 136 cases)		**36.50**	**22.77**	**20.74**	**22.04**	**20.35**	**19.27**	**19.54**	**17.09**	**16.43**

Table 4.11 The empirical constants obtained from the calibration of different beach conditions

Models	Empirical constants						
	all cases	plane beach	barred beach	stepped beach	sandy beach	small scale	large scale
Battjes and Janssen (1978)	0.42	0.36	0.40	0.69	0.61	0.39	0.59
Thornton and Guza (1983)	0.66	0.57	0.66	0.77	0.84	0.63	0.83
Stive model (1984)	0.47	0.52	0.41	0.52	0.52	0.47	0.51
Deigaard et al. (1991)	0.51	0.48	0.51	0.56	0.67	0.48	0.65
Karambas and Koutitas (1992)	0.62	0.68	0.42	0.49	0.63	0.60	0.63
Dally et al. (1985)	0.14	0.13	0.23	0.12	0.15	0.14	0.14
Rakha and Kamphuis (1995)	0.15	0.15	0.25	0.12	0.15	0.15	0.15
Rattanapitikon and Shibayama (1996)	0.17	0.16	0.25	0.14	0.17	0.17	0.17
Present (1999)	0.17	0.16	0.21	0.14	0.16	0.17	0.16

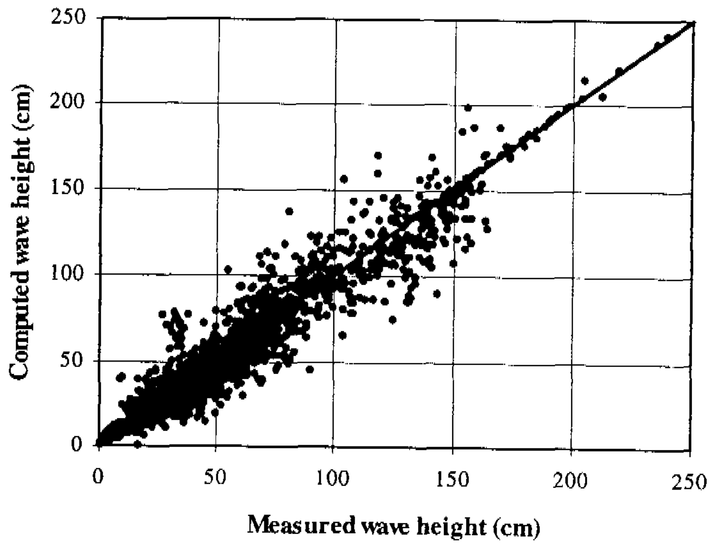

Fig. 4.5 Comparison between measured and computed wave height of the present model by using the experimental data in Table 4.1

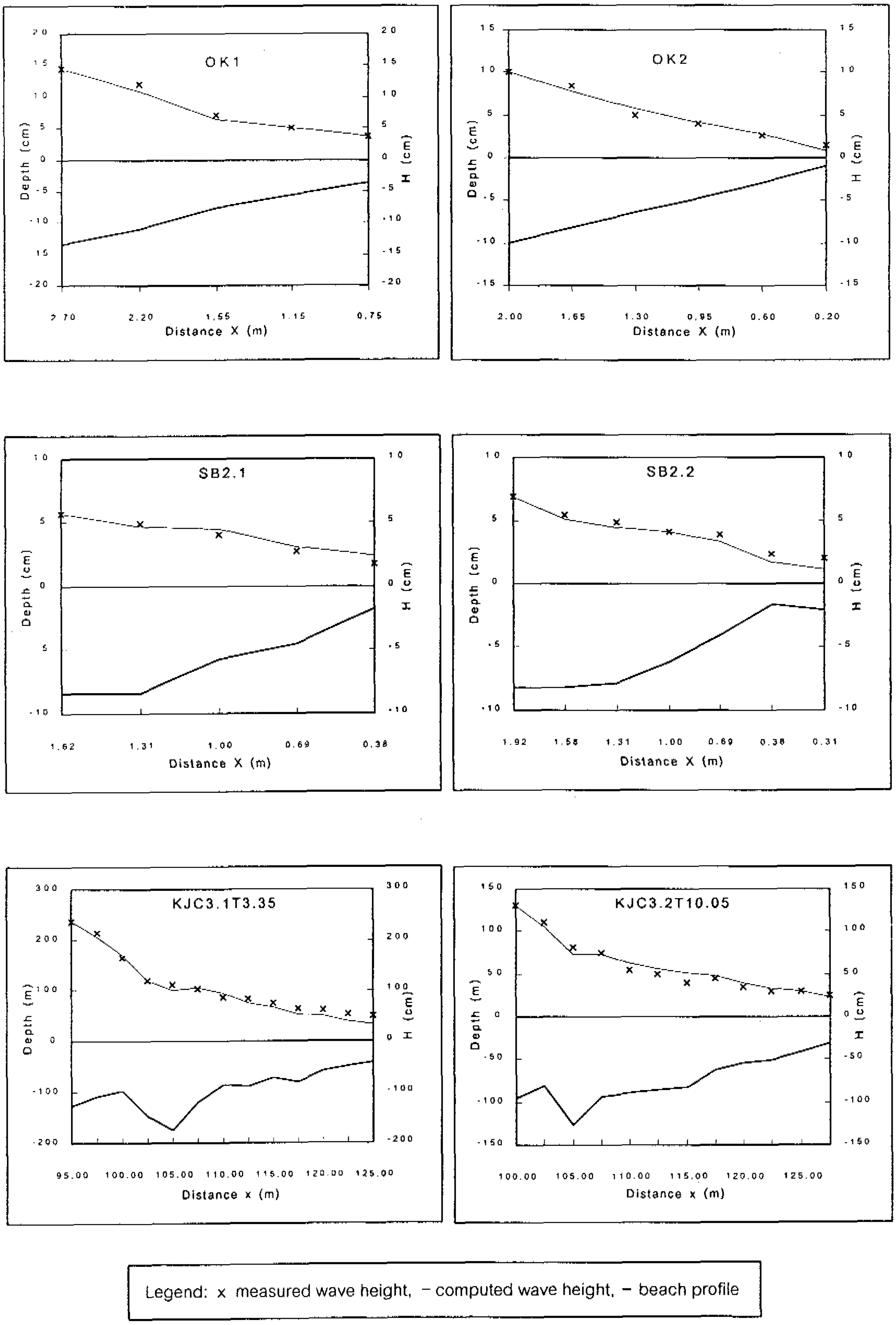

Fig. 4.6 Example of wave height transformation compared with experimental data of Okayasu (1988) case 1-2, Shibayama and Horikawa (1986) case 2.1-2.2 and Kajima et al. (1983) case 3.1-3.2