CHAPTER THREE

REYNOLDS STRESS IN SURF ZONE

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ABSTRACT

The on-offshore and the vertical components u, w of the velocity in a surf zone on a uniformly sloping beach in a wave tank were measured simultaneously with a laser-doppler velocimeter under two conditions. The time variation of the Reynolds stress -u'w' during one wave period is discussed. The Reynolds stress behaves as that in the oscillatory pipe flow does. The magnitude of the terms including the Reynolds stress terms in the on-offshore momentum equation is estimated. The Reynolds stress terms does not play any important role in the on-offshore momentum transfer during one wave period in the surf zone.

1. INTRODUCTION

In the 18th Conference on Coastal Engineering, Cape Town, 1982, an experimental result on the turbulence generated by wave breaking on beaches in wave tanks was presented(Sakai et al.(1982),(6)). The vertical distribution of the turbulent intensity inside the surf zone was shown. The effects of the breaker type on this distribution was discussed. The variation of the vertical distribution of the turbulent intensity during one wave period was also shown. It was explained by extending the turbulent wake theory.

Similar works can be found in Stive(1980)(7), Flick et al.(1981) (2) and Nadaoka et al.(1982)(5). The turbulent intensity is discussed there. In oscillatory pipe flow, the turbulence generated by the shear on the boundary plays an important role in the momentum transfer(3, 4) . The Reynolds stress term is balanced with the local acceleration term and the pressure gradient term.

In the surf zone, it is believed that the turbulence generated by the wave breaking plays an role in the transfer of heat and material such as the sediment and the waste. Whether the turbulence generated by the wave breaking plays a role in the on-offshore momentum transfer during one wave period or not ? Aono et al.(1981)(1) estimated the Reynolds stress in a surf zone on a horizontal bed in a wave tank. The data, however, are not sufficient to discuss this problem.

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To answer this question, an experiment under two conditions was done in a wave tank. The on-offshore and the vertical components u, wof the velocity inside a surf zone on a beach were measured simultaneously with a laser-doppler velocimeter. The turbulence $\underline{u'}$, w'generated by wave breaking was defined. The Reynolds stress -u'w' was estimated. Its time variation during one wave period and its role in the on-offshore momentum transfer during one wave period are discussed.

2. EXPERIMENTS

2.1 Experimental Arrangements

The experiment was done in a wave tank in Department of Civil Engineering, Kyoto University. The length of the tank is 30m, the width is 50cm, and the height is 70cm. This wave tank has glass walls on both sides in the central part. At the opposite end of the tank to a wave generator, a beach was installed.

A two-component laser-doppler velocimeter(abbreviated as LDV hereafter) was used to measure the water particle velocity field in the surf zone on the beach. The LDV used was a Spectra Physics Stabilite 15mW He-Ne laser, with a KANOMAX optical system 8143S and two data processors 8015(of the tracker type). This system utilizes the polarization of a laser beam in order to measure simultaneously two components of the velocity.

Since both sides of the wave tank has glass walls, the photodetector and the other optical system used were set separately on both sides of the tank. The system was operated in fringe mode with forward scatter. Due to limited space beneath the tank, the total optical system was installed on a frame hanging over the tank. This frame could move in both a vertical and a longitudinal direction.

The length of the laser tube was 1.0m, and the the length of the optical system was 60cm. It made the frame unstable if both the laser tube and the optical system were set horizontally in one line normal to the tank. The laser tube was, therefore, set vertically, and the laser beam was reflected horizontally using a mirror.

Two wave gauges were used to measure the water level variation in the surf zone.

2.2 Experimental Conditions

The experiment was done under 2 conditions. The experimental conditions of 2 cases are listed in Table 1. *i* is the beach slope, h_1 is the still water depth in the uniform depth region in front of the beach, *T* is the wave period, h_b is the still water depth at the wave breaking point, H_b is the breaking wave height, *W* is the surf zone width. In both cases, the waves broke on the beach. H_0/L_0 is the deepwater wave steepness. The breaker types were a spilling breaker in case 1 and a plunging breaker in case 2. Fig.l shows a comparison

of the size of the surf zone of two cases.

2.3 Experimental Procedures

The measurement of the velocity in case 1 was done in 6 positions. The deepest position was located 0.5m shoreward from the breaking point. The distance between the neighbouring positions was 0.5m. The thin vertical lines in Fig.1 show these positions. In case 2, the measurement of the velocity was done in 5 positions. The deepest position was located 45cm shoreward from the breaking point. The distance between the neighbouring positions was 5cm. The measurement in case 2 was done in a rather limited region. In each positions, the velocity was measured at about 7 levels from 1cm above the bottom to near the wave trough level.

case	i	h ₁ (cm)	T (sec)	hb (cm)		Hb (cm)
1 2	1/31 1/20	35.0	1.17	18	3.0 4.0	12.8 13.0
case	W (cm)	H ₀ /L ₀	breake type	er inst		trument
1 2	530 .275	0.063	spilling plunging		LDV LDV	



Fig.1 Surf Zone of 2 Cases

3. DATA ANALYSIS

The outputs from the wave gauges and the LDV were digitized every O.Olsec. The digitized data of the water level at the velocity measuring point, the on-offshore velocity, the vertical velocity and two dropout signals for two velocity components were plotted graphically. The time length of the plotted data was 48sec in case 1 and 70sec in case 2.

The time intervals in which the signal from the processor of the LDV did not drop out were determined. In these non-dropout intervals, the data of the two components of the velocity were moving averaged. The time width of this moving averaging was 0.1sec in case 1 and 0.2sec in case 2 (Fig.2). The turbulence(u' and w') was defined as the deviation of the original velocity from this moving averaged velocity (Fig.2).

At every 0.0lsec, a cross product of u' and w' can be calculated. This quantity with a minus sign may be called "an instantaneous Reynolds stress". In oscillatory pipe flow, the Reynolds stress is usually defined as an ensemble average of this instantaneous Reynolds stress at a fixed phase for many waves(3, 4). The Reynolds stress is, however, originally defined as a time average of the instantaneous Reynolds stress. The Reynolds stress was therefore defined here as a moving average of the instataneous Reynolds stress. The time width of this moving averaging was 0.1sec in case 1 and 0.2sec in case 2. As mentioned in the Introduction, here we are interested in the role of the turbulence during one wave period. The choice of this time width depends on this interest.

The Reynolds stress defined in this way was obtained every 0.01 sec in the non-dropout intervals for all waves. Now one wave period was divided into 12 sections of 0.1sec interval in case 1 and 18 sections in case 2(In Fig.2, which is only a sketch, one wave period is divided into 10 sections.). To see an average trend of the time variation of the Reynolds stress, an average value of the Reynolds stress values for all waves in each section was calculated.

4. TIME VARIATION OF REYNOLDS STRESS DURING ONE WAVE PERIOD

Fig.3 shows an example of the time variation of the Reynolds stress during one wave period at several levels in the position 2.0m shoreward from the breaking point in case 1. The top figure is an averaged wave profile during one wave period. One clear trend is seen at the upper two levels. At z = -1.7cm, the Reynolds stress changes from negative to positive after the crest phase. At z = -3.2cm, a similar change occurs before the crest phase.

Fig.4 is a different expression of Fig.3, the time variation of the vertical distribution of the Reynolds stress. Above mentioned trend is seen in the upper region near the crest phase. Aono et al. (1981)(1) reported a similar time variation of the Reynolds stress defined in a different way in a surf zone on a horizontal bed in a wave tank. In oscillatory pipe flow, it was found that the Reynolds stress takes a maximum when the mean flow velocity decreases(Hayashi et al.(1980)(3) and Hino et al.(1980)(4)). It seems that the Reynolds stress generated by the wave breaking in surf zone behaves as that in the oscillatory pipe flow does. Fig.5 shows an example of the time variation of the Reynolds stress in the position 55cm shoreward from the breaking point in case 2. The trend seen in Fig.3 is more evident.

The turbulence in the oscillatory pipe flow is a wall turbulence generated by the shear on the boudary. The turbulence in the surf zone is rather a free turbulence generated by the instability of the water surface. Considering this fact, there is no positive reason why the Reynolds stress in the surf zone behaves as that in the oscillatory pipe flow does.



Fig.2 Definition of Reynolds Stress

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Fig.3 Time Variation of Reynolds Stress during One Wave Period(Case 1)



10

15.0 (cm)

40

76

5.0

10.0



0 3.0

0

3.0 ş

0

0



Fig.5 Time Variation of Reynolds Stress during One Wave Period(Case 2)

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5. REYNOLDS STRESS TERM IN ON-OFFSHORE MOMENTUM EQUATION

5.1 Estimation of Magnitude of Terms

The on-offshore momentum equation is given as follows :

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial z} = \frac{1}{\rho} \frac{\partial}{\partial x} (-\rho - \rho \overline{u'^{2}}) + \frac{1}{\rho} \frac{\partial}{\partial z} (-\rho \overline{u'w'})$$
(1)

, where t is the time, x and z are two horizontal coordinates, u and w are two velocity components in x and z directions, ρ is the density of the fluid, p is the pressure, and $-\rho u'^2$ and $-\rho u'w'$ are two Reynolds stresses.

The magnitude of each term in Eq.(1) at one measuring point in case 2 is estimated by using the data obtained in the experiment. This point is located 5.5cm below the still water level and 60cm shoreward from the breaking point. As explained in 3., the Reynolds stress $-u^*w'$ is obtained every 0.1sec during one wave period. To compare the magnitude of each term in Eq.(1) every 0.1sec during one wave period, the values of u and w in each section of 0.1sec for all waves were averaged, and these averaged values in each section were used as u and w in Eq.(1). A root-meen-square value of u' value was used as $\overline{u'r'}$ in Eq.(1).

The value of the local acceleration term was estimated from a difference between the values of u in the neighbouring two sections. The value of the gradient in x direction was estimated from a difference between the values at this point and at the nearest point in the neighbouring offshore position. The phase difference between the values at two points was taken into account. The value of the gradient in z direction was estimated from a difference between the values at this point and at the point 1.0cm below in the same position. The value of the gradient term was not able to estimate due to a trouble of the wave gauges.

5.2 Comparison of Magnitude of Terms

Table 2 shows the result of the calculation. The time origin is at the crest phase. It is clear that the local acceleration term is large. It is supposed that the local acceleration term is balanced with the pressure gradient term which was not able to estimate. In the time interval t > 0.65sec(the wave trough phase), however, the local acceleration term becomes as small as the other terms. Fig.6 shows the time variation of two convection terms and two Reynolds stress terms. It is found that two Reynolds terms are smaller than two convection terms. Only in 0.5sec (t < 1.0sec, two Reynolds stress terms are as large as two convection terms.

For case 1, a simpler comparison of the magnitude of the convection term $u\partial u/\partial x$ and the Reynolds stress term $\partial u'w'/\partial z$ was done. The selected measuring point is located 4.2cm below the still water level and 1.5m shoreward from the breaking point. The comparison was

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made at an intermediate phase between the zero-up crossing phase and the creast phase. At this phase, u = 20 cm/sec.

The distance between this point and the neighbouring point is too long to estimate the x gradient. So the value of $\partial u/\partial x$ was estimated by using the small amplitude wave theory with the values of the wave period of 1.2sec, the still water depth of 15cm and the velocity amplitude of 30cm/sec. The estimated value of the convection term $u\partial u/\partial x$ is l4cm/sec. The Reynolds stress term $\partial u'w'/\partial z$ is estimated 4cm/sec, from the difference between the values at this point and at the neighbouring point in the same position. The Reynolds stress term is small again compared with the convection term.

Table 2	Comparison of Magnitude of Terms in On-Offshore
	Momentum Equation during One Wave Period in Surf
	Zone(Case 2, 5.5cm below still water level and 60cm
	shoreward from breaking point)

t	$\frac{\partial u}{\partial t}$	$u\frac{\partial u}{\partial x}$	$w \frac{\partial u}{\partial z}$	$\frac{\partial u'^2}{\partial x}$	du'w'
(sec)					
(sec) -0.25 -0.15 -0.05 0.15 0.25 0.35 0.45 0.55 0.65 0.75 0.85 0.95 1.05 1.15	91.8 135.8 49.9 -20.0 -56.3 -52.3 -58.8 -25.3 -6.7 13.4 -0.3 -4.7 -24.3 -5.6	5.3 0.3 -5.7 1.3 8.8 4.4 -0.5 0.5 3.1 3.8 1.7 1.7 1.8 2.9 0.6	m/sec 1.4 9.9 10.5 1.9 -1.2 -6.0 0.5 3.3 1.2 0.4 -0.1 0.4 -0.1 0.8 -0.0 -3.5	-0.3 -1.1 0.1 0.5 1.4 0.9 0.7 0.6 0.0 0.6 1.2 0.1 0.3 0.6 0.2	0.4 0.4 0.7 1.1 -0.0 0.4 0.9 1.3 -0.2 -1.1 0.2 1.1 1.4 1.3 0.7
1.25	-8.2	-2.1	-9.3	-0.2	0.0
1.45	-12.2		-5.3		0.4



Fig.6 Time Variation of Convection Terms and Reynolds Stress Terms in On-Offshore Momentum Equation during One Wave Period(Case 2, 5.5cm below still water level and 60cm shoreward from breaking point)

6. CONCLUSIONS

The on-offshore and the vertical components u, w of the velocity in a surf zone on a beach were measured simultaneously with a laserdoppler velocimeter in a wave tank under two conditions. The time variation of the Reynolds stress -u'w' during one wave period and its relative importance in the on-offshore momentum equation are discussed. The following conclusions are obtained :

(1) The Reynolds stress -u'w' changes from negative to positive near the crest phase. This is similar to the change of the Reynolds stress in the oscillatory pipe flow.

(2) Since the turbulence in the surf zone is a free turbulence generated by the instability of the water surface, there is no positive reason why the Reynolds stress in the surf zone behaves as that in the oscillatory pipe flow.

(3) The magnitude of the Reynolds stress terms in the on-offshore momentum equation during one wave period are small compared with the local acceleration term and the convection terms.

(4) The turbulence generated by wave breaking has no significant role in the on-offshore momentum transfer during one wave period in the surf zone.

7. REFERENCES

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