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EFFECT OF RAM MOMENTUM ON COMPACTION BY HEAVY TAMPING

EFFET PAR QUANTITE DE MOUVEMENT DE MOUTON SUR COMPACTAGE DE PILONNAGE INTENSIF

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SYNOPSIS: Some series of centrifuge model tests of heavy tamping suggested that ram penetration of sandy ground was governed predominantly by the ram momentum rather than by the kinetic energy of the ram. Further study based on actual field work and centrifuge model tests of heavy tamping, and large-scale tests of ram collision on a sand layer on the rock-shed model supports this idea. This idea is also found to apply to the ordinary laboratory compaction test.

INTRODUCTION

Heavy tamping has been successfully applied to the compacting of sandy and gravelly ground and waste landfill. The work conditions in the current design procedure, however, have been empirically determined because the effect of each governing factor, such as the ram mass, drop height, number of blows and the distance between tamping points, on compaction has not been sufficiently clarified.

To investigate the mechanism of compaction and the effect of factors of heavy tamping, the authors have employed the centrifuge model technique. Until now, some series of centrifuge model tests under various tamping conditions have suggested that ram penetration of the sandy ground is governed by the ram momentum rather than by the kinetic energy of the ram; that is, the ram mass is the predominant factor, followed by ram drop height and the number of blows (Mikasa et al. 1989).

This paper presents further study to elaborate the role of ram momentum on ram penetration of the ground based on field measurements and centrifuge model tests of heavy tamping and large-scale tests of ram collision on the rock-shed model. This tendency can be observed in the ordinary laboratory compaction test as well.

RAM PENETRATION

When a ram of mass m is released at a drop height H from the ground surface, it falls and impacts the ground at the initial velocity v_0 (= $\sqrt{2gH}$) and penetrates the ground as shown in **Fig. 1**. Assuming the ground is plastic and the ram does not rebound after collision– that is, the perfect inelastic impact– ram penetration of the ground is considered to be governed by the law of conservation of momentum, rather than by the law of conservation of energy, because of the large loss of energy due to plastic deformation of the ground and the emission of heat and sound.

According to the above law, the ram momentum mv_0 corresponds to the impulse integral of the ground. Thus,

$$\int_0^{t_f} F(t)\,dt = -mv_0 \qquad (1)$$

where t is the time; $t = 0$ is the time when the ram contacts the ground surface, t_f is the time when the ram rests, and $F(t)$ is the impact force, which changes during ram penetration as shown in **Fig. 2**. In the figure the shaded area corresponds to the ram momentum mv_0.

From the second law of motion,

$$F(t) = m\,\alpha(t) \qquad (2)$$

where $\alpha(t)$ is the vertical acceleration of the ram. Combining Eqs. (1) and (2),

$$\int_0^{t_f} \alpha(t)\,dt = -v_0 \qquad (3)$$

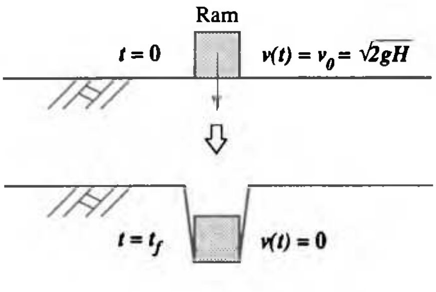

Fig. 1 Ram penetration

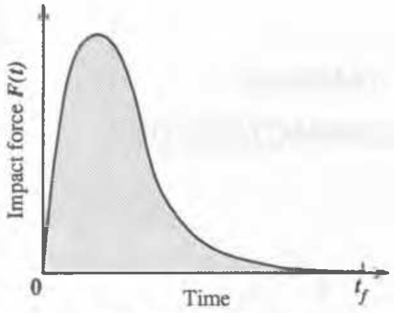

Fig. 2 Impact force

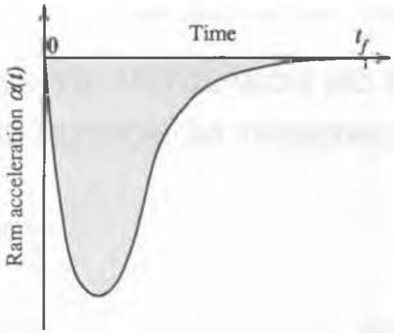

Fig. 3 Ram acceleration

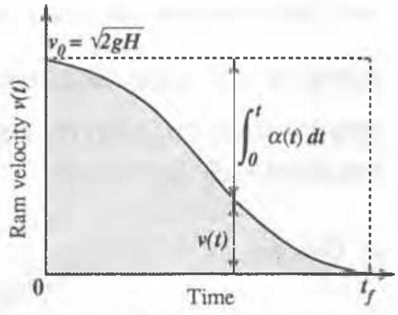

Fig. 4 Ram velocity

In this integration, the shaded are in **Fig. 3** corresponds to the initial ram velocity v_0. Since the integration of $\alpha(t)$ taken from 0 to t corresponds to the velocity decrease of the ram during penetration, the ram penetrating velocity $v(t)$ is expressed as

$$v(t) = v_0 + \int_0^t \alpha(t)\,dt \qquad (4)$$

The integration of $v(t)$ with respect to t produces the ram penetration $P(t)$. Thus the ultimate ram penetration P is

$$P = v_0 t_f + \int_0^{t_f}\int_0^t \alpha(t)\,dt\,dt \qquad (5)$$

The shaded area in **Fig. 4** corresponds to the ram penetration P, which is a part of the rectangular area $v_0 t_f$. Using this rectangular area, the ram penetration P can be simply expressed as

$$P = a\,v_0 t_f \qquad (6)$$

where a is the constant varying from 0 to unity with depending on the ground conditions. If the ground is loose a is assigned a larger value, and $a = 0.5$ when the waveform of $\alpha(t)$ is symmetrical with respect to the time $t_f/2$.

FIELD MEASUREMENT

The ram acceleration during penetration of the ground was measured in the field under the following conditions: the ground is sandy soil with an SPT N-value of around 5; the ram mass m is 25 t; the ram base area A is 4 m^2; and the drop height is varied as follows: 1, 2, 5 and 10 m.

Fig. 5 shows waveforms of ram acceleration. Maximum acceleration α_{max} increases with H. The impact duration t_f is almost the same irrespective of H. The initial slopes of the acceleration vs. time coincide. The relation between α_{max} and the square root of drop height $\sqrt{H}$ shows linearity, as shown in **Fig. 6**. This linear relation can also be derived from the following consideration: since the ram acceleration integral equals the initial velocity v_0 (= $\sqrt{2gH}$), if the values of t_f for different H are the same and the waveforms are similar, then α_{max} is proportional to $\sqrt{H}$.

Fig. 7 shows the results of another large-scale model test of ram collision conducted by Masuya et al. (1987) simulating the collision of the falling stone on the rock-shed. The shape of the ram base was spherical and the ram dropped onto a sand layer 90 cm thick placed on a thick concrete slab. Several values of the ram mass, ram base area and drop height were given as described in the figure. The figure shows that

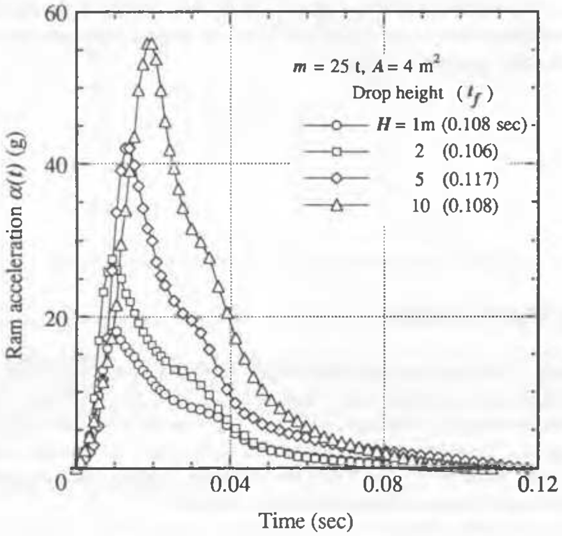

Fig. 5 Waveforms of ram acceleration

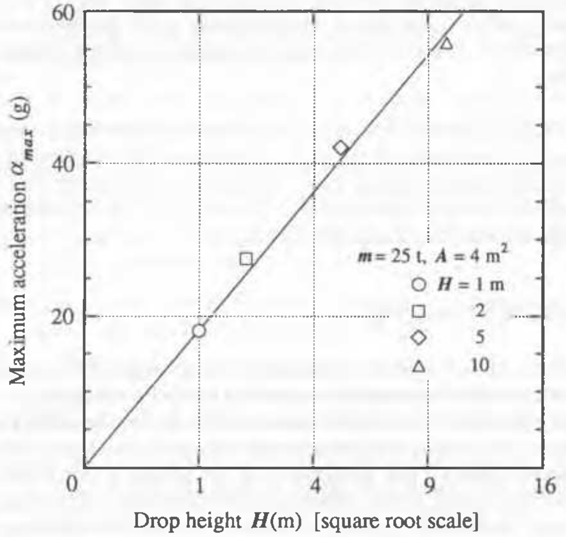

Fig. 6 Relation between maximum acceleration and drop height

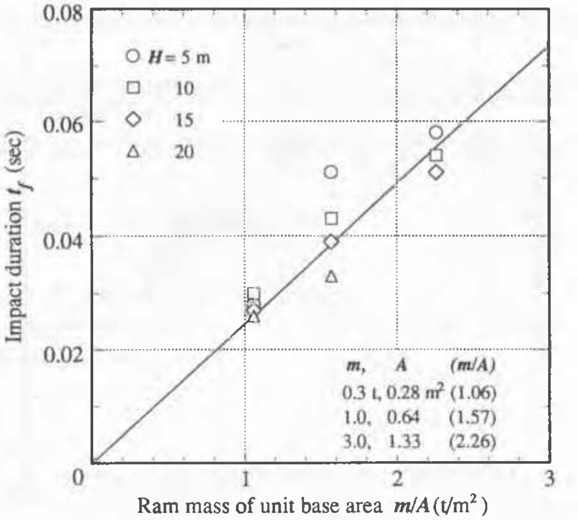

Fig. 7 Relation between impact duration and ram mass of unit base area

the impact duration t_f is approximately proportional to the ram mass of unit base area m/A, irrespective of H.

Yoshida et al. (1978) and Sasaki et al. (1983) reported the same tendency that t_f is not influenced by H. They also reported that α_{max} decreased with the increase in ram mass, and it increased with the increase in ram base area. These facts also support the tendency described above.

From the above consideration, the impact duration t_f can be written as

$$t_f = b\,\frac{m}{A} \qquad (7)$$

where b is the constant varying with the ground conditions. Combining Eqs. (6) and (7), P is expressed as

$$P = c\,\frac{mv_0}{A} \qquad (8)$$

where c is the constant varying with the ground conditions. Eq. (8) indicates that ram penetration P is proportional to the ram momentum and inversely proportional to the ram base area.

CENTRIFUGE MODEL TEST

A series of centrifuge model tests of heavy tamping were performed under a variety of tamping conditions. The model ground is a sandy soil compacted to the relative density of 50% and with a water content of 4%. The model is axi-symmetrical, and the semi-cylindrical model ground of 30 cm in diameter and 20 cm in height, as shown in **Fig. 8**, was employed so that the ground deformation was observed through a glass plate on the front face. Ram blows were applied directly onto the ground surface under a centrifugal acceleration of 100 g. The ram mass m, drop height H and number of blows N were combined so that the total tamping energy E_t is 8,000 tf-m (78.5 MJ) and the ram mass of unit base area m/A is 5 t/m², as shown in **Table I.**

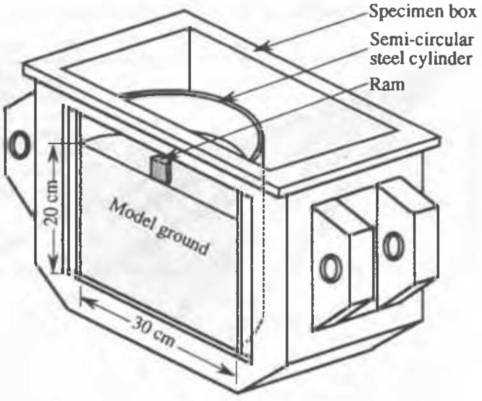

Fig. 8 Model ground

Table I Tamping conditions (in prototype scale)

Case	m (t)	H (m)	A (m²)	N	E_1 (tf-m) [MJ]	E_t (tf-m) [MJ]	mv_0 (tm/s)	mv_0/A (tm/s/m²)
1	10	10	2	80	100 [0.98]	8000 [78.5]	140	70
2	10	20	〃	40	200 [1.96]	〃	198	99
3	10	40	〃	20	400 [3.92]	〃	280	140
4	20	5	4	80	100 [0.98]	〃	198	49
5	20	10	〃	40	200 [1.96]	〃	280	70
6	20	20	〃	20	400 [3.92]	〃	396	99
7	20	40	〃	10	800 [7.85]	〃	560	140
8	40	5	8	40	200 [1.96]	〃	396	49
9	40	10	〃	20	400 [3.92]	〃	560	70
10	40	20	〃	10	800 [7.85]	〃	792	99
11	40	40	〃	5	1600 [15.7]	〃	1120	140
12	80	5	16	20	400 [3.92]	〃	792	49
13	80	10	〃	10	800 [7.85]	〃	1120	70
14	80	20	〃	5	1600 [15.7]	〃	1584	99

m : ram mass, H : drop height, A : ram base area, N : number of blows
E_1 : energy per blow, E_t : total energy,
mv_0 : ram momentum, mv_0/A : ram momentum per unit base area

Fig. 9 shows the relations between the ram penetration P_N (accumulated value in the prototype scale) and the square root of N for all cases, in which P_N is corrected considering the collapse of the wall of the tamping hole based on the previous observation that the diameter of the tamping hole at the ground surface is proportional to $\sqrt{N}$. All P_N - $\sqrt{N}$ relations are linear as reported previously (Mikasa et al. 1988). The figure indicates that the P_N - $\sqrt{N}$ relations having the same mv_0/A value are almost the same. The number of blows required for a certain penetration decreases to one-fourth when mv_0/A is doubled.

From this series of tests, the following P_N - $\sqrt{N}$ relation can be derived:

$$P_N = c\,\frac{mv_0}{A}\sqrt{N} \qquad (9)$$

The average value of c in this test series is 8.3 x 10^{-3} (m²/t)s.

Fig. 10 shows the increase of the volume of tamping hole V_c in the prototype scale against $\sqrt{N}$. The figure shows that V_c is also proportional to $\sqrt{N}$, and the V_c - $\sqrt{N}$ relations with the same mv_0 value are approximately equal.

Using the relation $V_c = P_N A$, Eq. (9) is written as follows:

$$V_c = c\,mv_0\sqrt{N} \qquad (10)$$

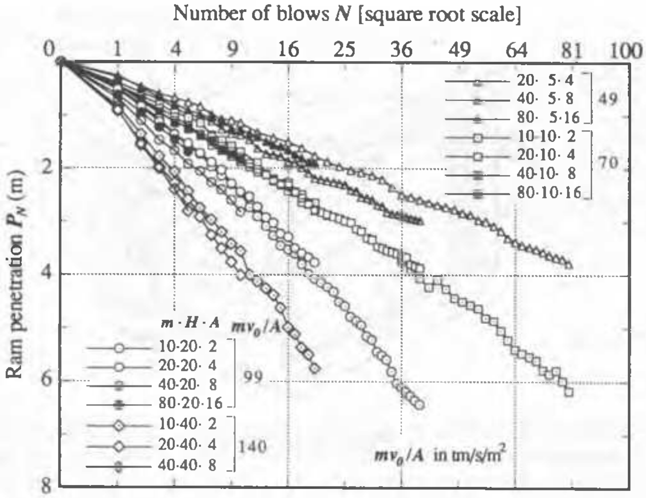

Fig. 9 Relations between ram penetration and number of blows

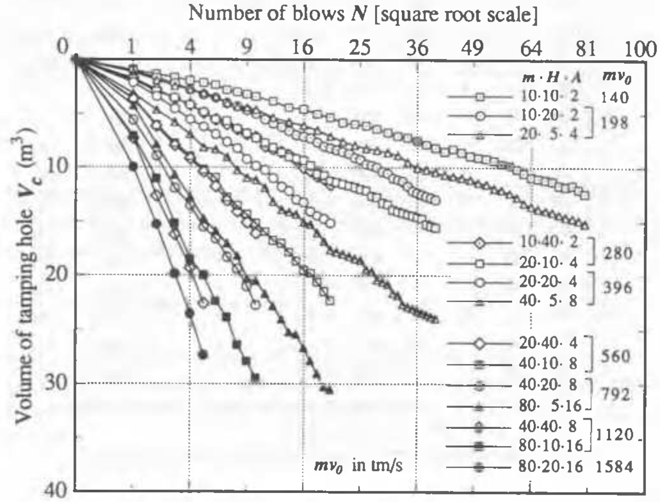

Fig. 10 Relations between volume of tamping hole and number of blows

Previous work (Oshima et al. 1991) which employed a different ram base area with a constant ram mass suggested the same relations as expressed by Eqs. (9) and (10).

LABORATORY COMPACTION TEST

The above consideration that the ram mass has the predominant effect on the compaction was found to apply to the ordinary lab compaction test. In the mold of 15 cm in diameter, a gravelly soil of 38-mm maximum particle size and 10% finer than 0.075 mm was compacted under the following tamping conditions: the ram mass m and the drop height H were combined so that each blow has the same kinetic energy of 75 kgf-cm (7.36 J), that is, [m, H] = [5 kg, 15 cm], [2.5, 30], [1.75, 43], [1, 75], [0.75, 100]; the number of blows applied to each of the 3 layers is 55.

Fig. 11 shows compaction curves for all cases, in which the dry density increases with the ram mass, showing that the ram mass, rather than the drop height, has the predominant effect on compaction. This tendency suggests the importance of the role of ram momentum on the compaction in the mold.

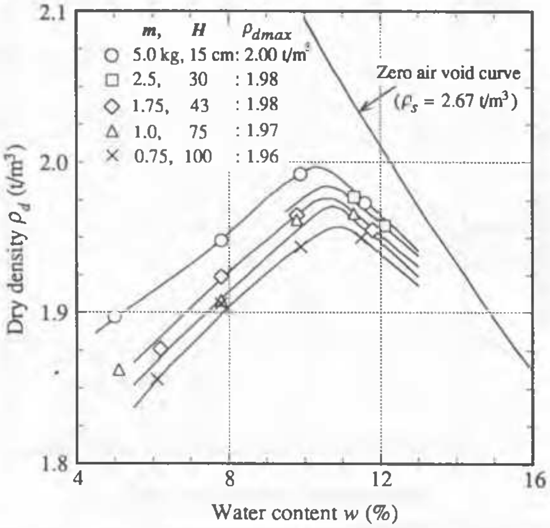

Fig. 11 Compaction curves

CONCLUSIONS

The results of measurement of the actual field work and centrifuge model tests of heavy tamping, ram collision tests of the rock-shed model and the laboratory compaction tests lead to the following conclusions:

The period of ram impact is proportional to the ram mass of unit base area and is not influenced by the ram drop height. The maximum acceleration of the ram during penetration of the ground is proportional to the square root of the drop height. These facts suggest that the ram penetration is governed predominantly by the ram momentum of unit base area rather than the kinetic energy. This tendency is also observed in the laboratory compaction tests.

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