The static formation of ACV three-dimensional bag-finger skirt

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RÉSUMÉ

La jupe composée d'un sac et d'éléments en forme de doigts est largement utilisée sur les aéroglisseurs tant amphibies qu'à quilles latérales. La théorie relative aux forces statiques qui agissent sur un modèle à deux dimensions figurant une telle jupe est déjà établie; toutefois, elle ne permet pas de décrire de manière rationnelle les forces qui s'exercent sur la jupe dans la partie arrondie de la proue et de l'arrière.

Cette communication présente la théorie concernant le modèle tridimensionnel correspondant de la jupe. Cette théorie a été validée aussi bien par des expérimentations sur un modèle de la jupe que par des essais sur des jupes en vraie grandeur.

Elle décrit une méthode de prévision de la géométrie d'une jupe en fonction des forces en jeu et présente certains éléments du modèle de jupe à trois dimensions.

THE STATIC FORMATION OF ACV THREE-DIMENSIONAL BAG-FINGER SKIRT

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ABSTRACT

The bag-finger skirt is widely used in ACV both in amphibious and sidewall craft. The fundamental theory about the static formation of ACV two-dimensional bag-finger skirt was already established, but it couldn't analyse the round bow and the circular stern of the skirt rationally.

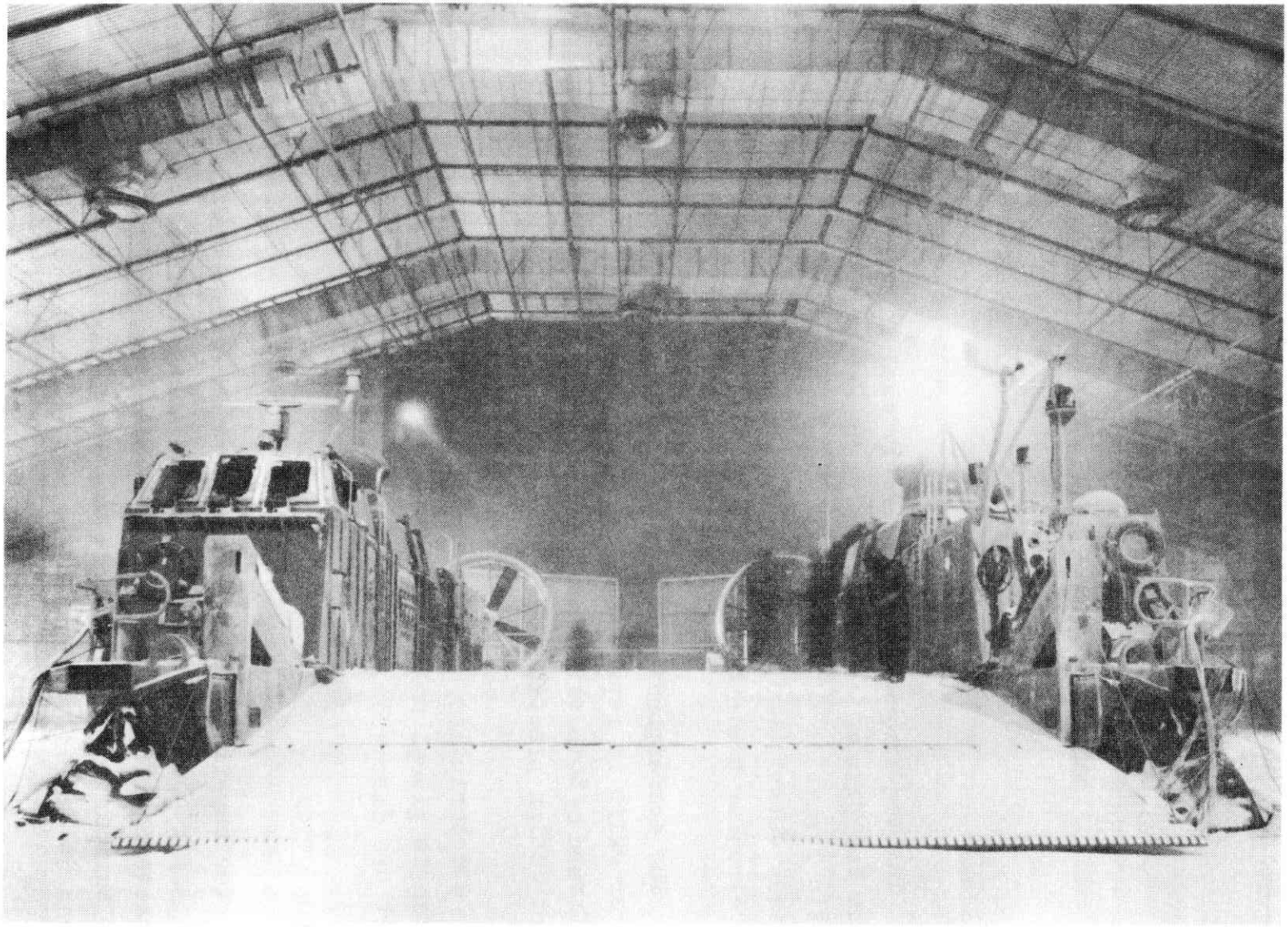
The corresponding theory of the three-dimensional bag-finger skirt is represented in this paper. This theory has been comfirmed by both skirt model experimental results and full scale skirt design practice.

A description of the calculation of a skirt geometry formation is given, and some feature about three-dimensional skirt are discussed.

INTRODUCTION

The bag-finger skirts have come into wide use in modern ACV with their good performance. It is because of the deflection characteristic of skirt that the obstacles over land can be easy surmounted by hovercraft and the impacts of waves against it can be weaken, thus the wave resistance can also be largely reduced.

With doing large amount of experimental and theoretical research work in a laboratory of MARIC, the analysis of the



static forces acting on two-dimensional bag-finger skirt and three-dimensional one was complected and their mathematical models were established in the early days of 1980s, but only two-dimensional theory has been presented. 1). The utility programs based on these models have been developed and used for researching and designing ACV bag-finger skirts.

The two-dimensional skirts, in general, are taken in the side region of hovercraft or the flat part of bow and stern, but in the region of round bow or circular stern corner have to be taken the three-dimensional skirts. Because there are some differences in analysis of the forces between above mentioned two sorts of skirt, the produced error should not be neglected if the three-dimensional skirt is designed by means of the two-dimensional skirt theory.

A common understanding of these two sorts of skirt theory, hoverever, can be reached completely, because the two-dimensional skirt is only a particular condition, or a limit, of the three-dimensional skirt.

In resent years the three-dimensional skirt theory has been developed. This paper represents the theory on formation of three-dimensional skirt, in which not only the three-dimension geometry and the torus-bag tension but also the lateral force in inner bag arc are taken into account.

TENSION OF THE THREE-DIMENSIONAL SKIRT BAG

A three-dimensional skirt is different from a two-dimensional skirt not only in geometry but in calculation of the bag tension as well. A part of the bag of three-dimensional skirt filled with pressure air can be regarded as a part of a torus container with thin shell structure which can bear internal pressure, as shown in Fig.1.

The tension formulae of the torus container have been represented in relevant book 2) . Making a change in those formulae, the tangential tension Tc which acts on the point C of the torus container along the tangent line in the vertical symmetrical plane, and the lateral tension Tc' which acts on the same point along the tangent line in the horizontal plane, can be obtained as following.

$$Tc = \frac{PR}{2}\left(1 + \frac{Ro}{Rc}\right) = \frac{PR}{2}\left(1 + \frac{Ro}{Ro+R\cos\varphi_1}\right) \quad \cdots\cdots\cdots \quad (1)$$

$$Tc' = \frac{PR}{2} \quad \cdots\cdots\cdots\cdots \quad (2)$$

where P is the internal gauge pressure, and R is the curvature radius of the torus section in the vertical symmetrical plane. Ro and Rc represent the vertical distances from the symmetrical axis of the torus container to the point O_1 and C respectively.

In order to make a comparison of the tension formulae between the three and two-dimensional conditions, the formula (1) is changed in writing as follows,

$$Tc = K_r PR \quad \cdots\cdots\cdots \quad (3)$$

where

$$Kr = \frac{1}{2}\left(1+\frac{Ro}{Rc}\right) = \frac{1}{2}\left(1 + \frac{Ro}{Ro + R\cos\varphi_1}\right) \quad \cdots\cdots\cdots \quad (4)$$

The value of factor Kr, which is called the three-dimensional bag tension factor, varies with the ratio of the Ro to Rc. Because, for practical purposes, there is no need to discuss the condition in which Rc is less than Ro, as both Ro and Rc tend to infinite, the value of Kr reaches the maximum 1. That is the two-dimensional condition, the limit of the three-dimensional condition. As Ro tends to R, the value of Kr is

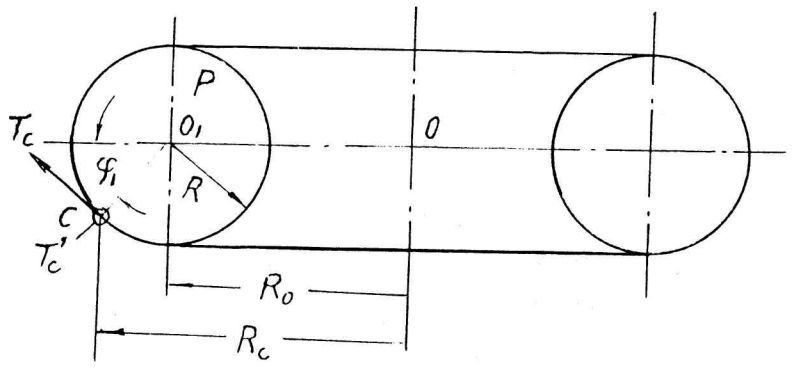


Fig. 1

equal to $(\frac{1}{2})[1 + (R/Rc)]$ or $(\frac{1}{2})[1 + (1/(1 + \cos\varphi_1)]$. In this condition the value of Kr is minimized, and the influence of the three-dimensional shape upon the tension of torus container becomes maximum.

As Rc is equal to Ro (i.e. as the angle φ_1 is 90^o) the value of Kr is also equal to 1. In other words, it is in this point of the torus container that the tension is not influenced by its three-dimensional shape.

As Rc is equal to (Ro + R) (i.e. the angle φ_1 is 0^o), the value Kr is equal to $(\frac{1}{2})[1 + Ro/(Ro + R)]$.

It is obvious that because of influence of the three-dimensional shape the bag tension of three-dimensional skirt is reduced, as compared with the corresponding two-dimensional skirt.

STATIC FORCES ANALYSIS

If neglecting the effect of skirt material stiffness, the three-dimensional bag-finger skirt under pressure is taken the shape like in Fig.2. Scalloping the skirt with the differential angle $\Delta\varepsilon$ vertically and taking the finger triangle block as the free body, the resultant forces acting on it in the vertical symmetrical plane and the geometric parameters of the skirt are also shown in Fig. 2a. These resultant forces are represented as follows,

$$\left.\begin{aligned} T1 &= Kr_1 PbR_1 Rc\Delta\varepsilon \\ F1 &= (Pb - Pc)\, A1 \\ F2 &= PcA_2 \\ F3 &= \tfrac{1}{2}(Pb - Pc)\, R_2 \Delta\varepsilon R_2\vartheta_2 \\ W &= K_4 GRc\Delta\varepsilon \end{aligned}\right\} \quad \cdots\cdots\cdots(5)$$

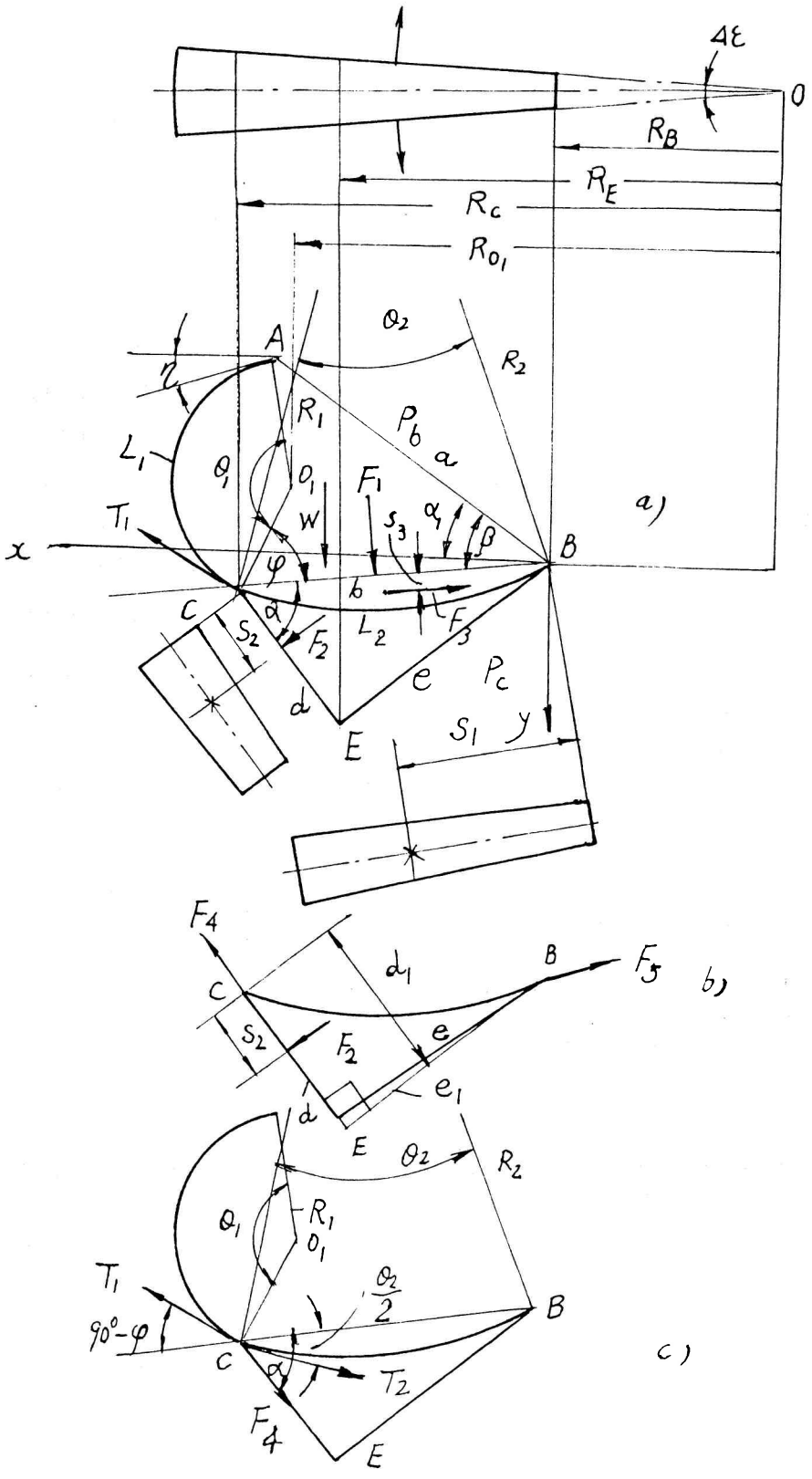

Δε
0
R_B
R_E
R_C
R_{01}
A
θ_2
R_2
η
R_1
P_b
a
L_1
θ_1
O_1
F_1
W
S_3
α_1
β
a)
T_1
x
φ
B
b
C
α
S_2
F_2
L_2
F_3
e
P_c
d
E
S_1
y
F_4
d_1
B
F_5
b)
C
S_2
F_2
e
e_1
d
E
θ_2
R_2
θ_1
R_1
O_1
T_1
$\frac{\theta_2}{2}$
B
$90°-\varphi$
C
α
T_2
F_4
E
c)

Fig. 2

where T1 is the tension of the bag arc, F1 is the resultant force of the pressure difference acting on the inner bag arc, F2 is the resultant force of the cushion pressure acting on the outward slide of the finger, F3 is the resultant force of lateral tension of the inner bag, which is projected on the symmetrical plane, W is the gravity of the free body skirt material. On the other hand, Pc is the cushion pressure, and Pb is the pressure in bag. R1 and R2 is the curvature radius of the bag arc and the inner bag arc respectively. θ_2 is the centrical angle of the inner bag arc. G is the gravity of the free body skirt material per meter width corresponding to the two-dimensional skirt. K4 is the correlative gravity coefficient with the three-dimensional skirt. The ares of the differential trapezoids A1, A2, the coordinates of the centroids S1, S2, and the coordinate of the centroid of inner bag arc are as follows

$$\left.\begin{aligned} A1 &= \tfrac{1}{2}\, b\, (Rc + R_\beta)\Delta\varepsilon \\ A2 &= \tfrac{1}{2}\, d\, (Rc + R_\varepsilon)\Delta\varepsilon \\ S1 &= \frac{b}{3}\,\frac{(2Rc + R_\beta)}{(Rc + R_\beta)} \\ S2 &= \frac{d}{3}\,\frac{(Rc + 2R_\varepsilon)}{(Rc + R_\varepsilon)} \\ S3 &= R2\left(\frac{\sin\frac{\theta_2}{2}}{\theta_2/2} - \cos\frac{\theta_2}{2}\right) \end{aligned}\right\} \quad \cdots\cdots\cdots(6)$$

The moments of the forces acting on the free body to point B are given,

$$\left.\begin{aligned} M_{T_1} &= -T1\ b\cos\varphi \\ M_{F_1} &= F1\ S1 \\ M_{F_2} &= F2\ (b\cos\alpha - S2) \\ M_{F_3} &= F3\ S3 \\ Mw &= GKmb\cos(\beta - \alpha_1) \end{aligned}\right\} \quad \cdots\cdots\cdots(7)$$

where Km is the location facter of the gravity center. Thus the

moment equation for geometry formation of the bag-finger skirt is

$$\Sigma M = M_{T_1} + M_{F_1} + M_{F_2} + M_{F_3} + M_W = 0 \quad \ldots\ldots\ldots (8)$$

SKIRT GEOMETRY FORMATION EQUATION

The geometry formation equation of three-dimensional skirt can be obtained from equation (1),(2),(3),(4) such as below,

$$Kr1R1\cos\varphi = K1\,\frac{b}{2}(1-Pcb) + Pcb\cdot d\,(K2\cos\alpha - K3\,\frac{d}{2b}) + K4Km\frac{G}{Pb}\cos(\beta-\alpha) + \tfrac{1}{2}(1-Pcb)\frac{R2^3\theta_2}{bRc}\left(\frac{\sin\frac{\theta_2}{2}}{\theta_2/2} - \cos\frac{\theta_2}{2}\right) \ldots\ldots\ldots\ldots (9)$$

where Pcb is Pc/Pb ratio and the coefficients of three-dimensional bag-finger skirt are as follows,

$$\left.\begin{aligned} K_{r1} &= \tfrac{1}{2}\left(1 + \frac{Rq1}{Rc}\right) \\ K1 &= 1/3\,\left(2 + \frac{R\beta}{Rc}\right) \\ K2 &= \tfrac{1}{2}\,\left(1 + \frac{R\varepsilon}{Rc}\right) \\ K3 &= 1/3\,\left(1 + 2\frac{R\varepsilon}{Rc}\right) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (10)$$

In the two-dimensional condition, obviously, each and every coefficient in equation (9), Kr1, K1, K2, K3, K4 is equal to 1, except that the last term is equal to 0. Thus the equation (9) has become such as below,

$$R_1\cos\varphi = \frac{b}{2}(1-Pcb) + Pcb\cdot d(\cos\alpha - \frac{d}{2b}) + \frac{KmG}{Pb}\cos\,(\beta-\alpha_1) \quad \ldots(11)$$

The curvature radius R2 and the centrical angle θ_2 can be determined by analysing the forces acting on the finger and on point C. The tension of the inner bag arc,

$T2 = (Pb - Pc)\,R2Kr2Rc\Delta\varepsilon$

where $Kr2 = \frac{1}{2}(1 + \frac{Ro2}{Rc})$.

The three forces F2, F4, F5, which acting on the finger should converge to a point in the vertical symmetrical plane, as shown in Fig.2b,

$$\left.\begin{aligned} F4 &= F2\,\frac{d1 - S2}{e1} \\ F5 &= F2\,\frac{\sqrt{(d1-S2)^2 + e1^2}}{e1} \end{aligned}\right\} \quad \cdots\cdots\cdots \quad (12)$$

The equation of equilibrium of forces acting on point C, shown in Fig.2c, is

$$\left.\begin{aligned} T2\cos\frac{\theta_2}{2} &= T1\sin\varphi - F4\cos\alpha \\ T2\sin\frac{\theta_2}{2} &= T1\cos\varphi - F4\sin\alpha \end{aligned}\right\} \quad \cdots\cdots\cdots \quad (13)$$

hence

$$\left.\begin{aligned} \operatorname{tg}\frac{\theta_2}{2} &= \frac{T1\cos\varphi - F4\sin\alpha}{T1\sin\varphi - F4\cos\alpha} \\ R2 &= L2/\theta_2 \end{aligned}\right\} \quad \cdots\cdots\cdots \quad (14)$$

As the pressure ratio Pcb tends to 1, the resultant force of the lateral tension of inner bag tends to 0. Thus in a range of Pcb which is near by 1, the last term of equation (9) may not be taken into account.

The shape of a skirt at certain pressure ratio Pcb can be determined by equation (9) and (13)if the skirt geometric parameters and the locations of inner and outer attachment points are given. The other way round, the geometric parameters of a skirt can also be found according to the requirement for the skirt shape.

COMPARISION OF THE CALCULATION AND THE EXPERIMENT

Experiments on geometry formation of a three-dimensional skirt model at pressure ratio Pcb = 0.87 were conducted in a rig both on water surface and on rigid floor. The geometric parameters of the skirt used for these experiments are given in table 1, in which the lengthunit is meter and the angle unit is radian.

Table 1. Geometric parameters of a skirt

R_1	a	α_1	L1	b	d	α
0.200	0.224	0.464	0.1637	0.257	0.110	0.873

The scalloped skirt model with centrical angle 60° consisted of four bag-sections and eight fingers. The specific gravity per unit area of the skirt material is 1.07 Kgf/m^2. The experiments results and the corresponding theoretical calculation are shown in Fig.3. The theoretical calculation shows good agreement with the experimental result.3).

COMPARISON OF SKIRT FORMATION BETWEEN TWO AND THREE-DIMENSIONAL CONDITIONS

Taking a full scale skirt for example, according to the requirement for locations of the points A, B, C, E, the geometric parameters of the skirt at a certain pressure can be found. A calculation of the skirt formation in both two and three-dimensional conditions is given, as shown in table 2 and Fig.4.

Table 2.A calculation of a skirt formation

condition	X_A	Y_A	X_C	Y_C	X_E	Y_E	P_{cb}	R_B
two-dimensional	1.225	-0.670	2.125	0.350	1.075	1.050	0.95	∞
three-dimensional	1.225	-0.670	2.125	0.350	1.075	1.050	0.95	1.1
condition	Xo	Yo	R1	θ1	L1	$-\eta$	$\Delta y_E / \Delta P_{cb}$	
two-dimensional	1.582	-0.078	0.691	2.781	1.923	6.543	-0.392	
three-dimensional	1.633	-0.123	0.682	2.976	2.031	0.640	-0.329	

where η is the angle between the tangent line of the bag arc $\overset{\frown}{AC}$ and the level line at point A (as shown in Fig.2). $\Delta y_E / \Delta P_{cb}$ is the vertical deflection factor of skirt.

The calculation indicated that in three-dimensional condition the bag-arc length L1 and the angle $-\eta$ increased, the bag protruded upwards and outwards, besides, the vertical deflection factor $|\Delta YE/\Delta Pcb|$ decreased, as compared with the corresponding two-dimensional condition.

In fact, the vertical deflection of two-dimensional skirt is not be restricted, but the deflection of three-dimensional skirt is restricted severely by structure itself, especialy in the downward direction, therefore the calculated value of deflection is not conforme to reality, and the practical value is reduced greatly.

Because there is above mentioned differences between two and three-dimensional conditions, the trouble comes into being with harmonized skirt deformation in the region where both two and three-dimensional skirt have common boundary. It may be overcome by means of extending the transitive section in the region for practical engineering design.

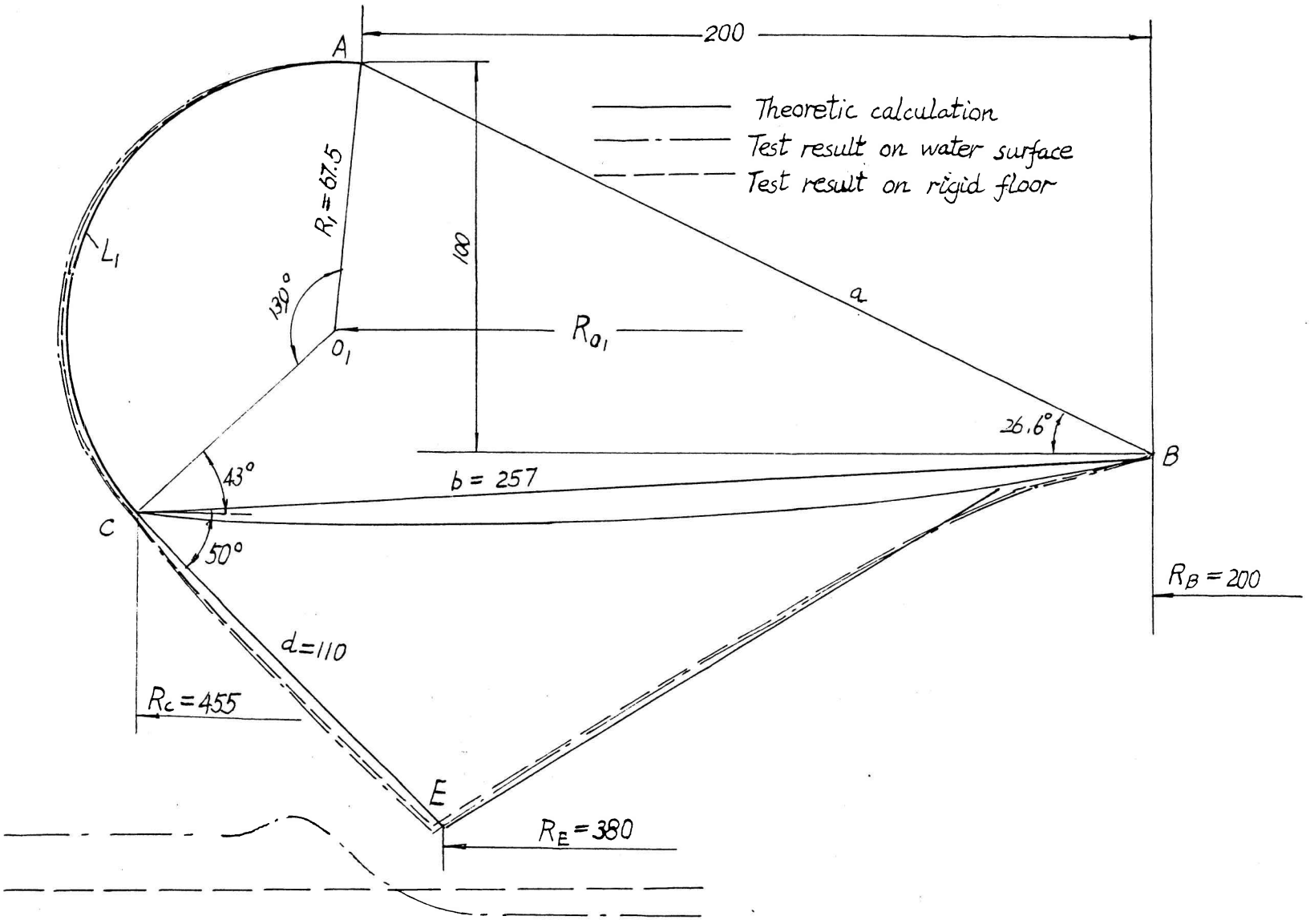

200
A
Theoretic calculation
Test result on water surface
Test result on rigid floor
$R_1 = 67.5$
L_1
130°
100
R_{01}
O_1
a
26.6°
B
43°
b = 257
C
50°
$R_B = 200$
d=110
$R_C = 455$
E
$R_E = 380$

Fig. 3

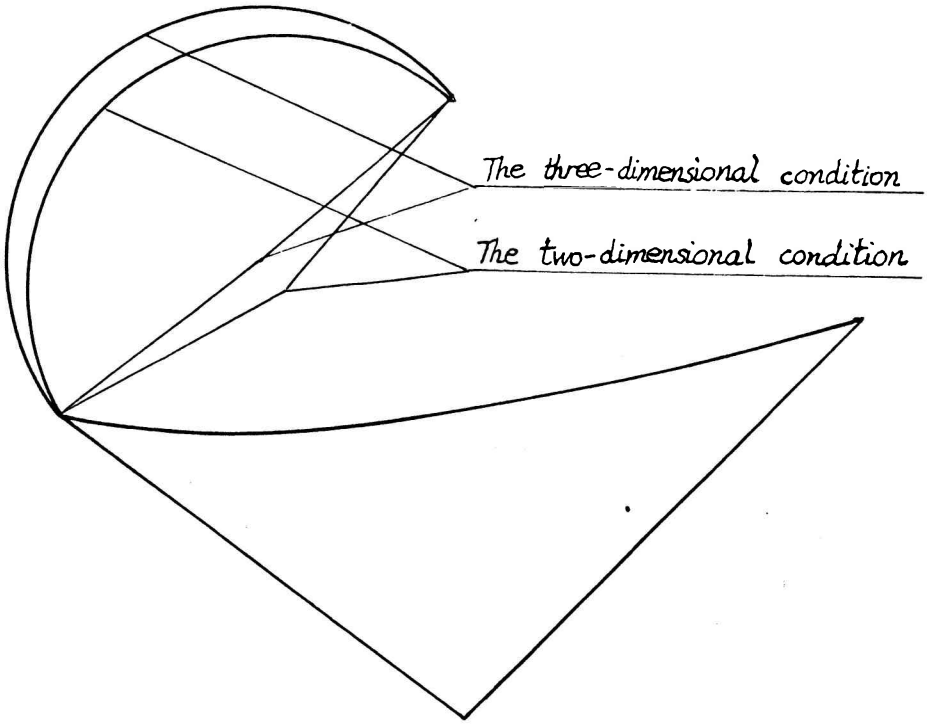

The three-dimensional condition
The two-dimensional condition

Fig. 4

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