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Development of Prediction Equations of Flared Skirts' Appearance from Various Drape Coefficients

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Abstract

Prediction equations of appearance of flared skirts are derived by the multiple regression of various drape coefficients with subjectively evaluated data which was obtained from observation of a walking model wearing each skirt. The subjective data was obtained for 9 evaluation terms of moving flared skirt by SD method evaluated by 23 university students aged from 19 to 22. It was found that "flowing", "rhythmical", "blowy", "airy", "flexible", "graceful", "lively", "dynamic" and "beautiful" movement of flared skirts are evaluated objectively from a combination of various drape coefficients. These equations were inspected by the other 9 flared skirts and were proved to be reliable. Only 4 terms such as "rhythmical", "airy", "graceful" and "beautiful" are enough to evaluate the appearance. Almost all the evaluation terms were primarily dominated by conventional static drape coefficient (D_s) of fabrics.

Key Words: Drape coefficient, Objective evaluation, Appearance

1. Introduction

The aesthetic appearance of flared skirts is recognized by their moving state on human body. In the former work, objective evaluation equations for the appearance of swinging flared skirts were developed by the authors [1]. More handy equations were also developed from various drape coefficients and shown in the last symposium [2]. However, those equations have been derived from subjective evaluation of swinging skirts on simulated mannequin stand. Therefore, subjective evaluation of swinging skirts on a model (real walking woman) was carried out in this paper and the prediction equations were developed.

2. Experimental

2.1 Samples

Fabric samples used in this experiment are used mainly for women's skirts and/or fine dresses. The flared skirt used in this study had four gore panels, and each panel was cut on the fabric's true bias. Seventeen flared skirts, one from each fabric, were prepared to fit a mannequin with a 60 cm waist and an 88 cm hip. The skirt length was 70 cm and the hem circumference was 260 cm. The waistline seam allowance was 1.0 cm, with 1.5 cm for the seams joining the gores. The hem depth was 4.0 cm. The stitch length used by the professional dressmaker who made the skirts was 5 per cm or 0.2 cm each. Details of fabric samples are shown in Table 1 and mechanical parameters are shown in Table 2.

2.2 Subjective evaluation of moving flared skirts on a model

The appearance of flared skirts worn by a walking model was evaluated by SD (Semantic Differential) method [3]. The model was selected to fit the skirts. The model walked for 2 round trips with 10 steps in one way. The length of a step was 64 cm and the walking velocity was 91.4 cm/s. Appearance of moving skirts was evaluated by 23 female students of Ehime university by SD method using paired antonym evaluation terms such as; "flowing vs. still", "rhythmical vs. flat", "blowy vs. droop", "airy vs. grave", "flexible vs. hard", "graceful vs. coarse", "lively vs. dead", "dynamic vs. delicate" and "beautiful vs. plain". These terms were used to evaluate the movement of flared skirts in our previous investigations [1, 4-6]. The order of evaluation terms was arranged randomly and the paired antonym was put also randomly in right and left to get independent evaluation. The flared skirt was

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Table 1 Details of Fabric Samples for Flared Skirts.

Sample Symbol	Fabric Name	Density (/m)		Count (tex)		Twist (/m)		Weight (g/m²)	Thickness* (mm)
		Warp	Weft	Warp	Weft	Warp	Weft		
A	Silk Dechine	6200	4200	3.4	7.2	＜100	3600	55.8	0.200
B	Silk Chirimen	7300	1600	7.5	74.4	＜100	1600	161.0	0.738
C	Silk Fujiginu	4400	3600	7.1	7.9	1100	1000	58.0	0.237
D	PET Dechine a	6800	4000	9.5	9.8	＜100	1200	100.7	0.310
E	PET Chirimen a	3600	3300	15.8	16.7	900	2400	159.4	0.708
F	PET Viella	4000	4000	14.4	14.3	1100	＜100	106.5	0.354
G	Rayon	4200	3000	8.1	14.4	＜100	＜100	78.2	0.153
H	Cupra	5800	4100	5.7	7.1	＜100	＜100	62.4	0.128
I	Nylon	3900	3700	7.6	7.6	＜100	＜100	71.6	0.170
J	Cotton a	3200	3100	14.5	14.2	1300	1900	129.6	0.545
K	PET Dechine b	3700	3300	6.7	16.7	＜100	1800	111.8	0.262
L	PET Dechine c	3700	3300	6.7	16.7	＜100	1800	105.6	0.243
M	PET Dechine d	3700	3300	6.7	16.7	＜100	1800	111.2	0.254
N	PET Dechine e	3700	3300	6.7	16.7	＜100	1800	109.3	0.244
O	PET Chirimen b	5200	2200	6.1	4.3	＜100	3200	162.3	0.671
P	Cotton b	5400	4700	12.4	14.0	300	500	237.8	0.730
Q	Cotton c	5300	3000	6.4	7.4	1100	1400	146.1	0.358

*Thickness is measured at the pressure of 49 Pa.

Table 2 Mechanical Parameters of Fabric Samples for Flared Skirts.

Sample Symbol	B (mN·m²/m)	2HB (mN·m/m)	G (N/m/rad)	2HG (N/m)
A	0.0028	0.057	14.05	0.157
B	0.0078	0.427	18.54	0.676
C	0.0018	0.080	16.29	0.235
D	0.0016	0.034	14.61	0.098
E	0.0023	0.078	24.58	0.368
F	0.0035	0.103	15.17	0.196
G	0.0044	0.201	21.07	0.032
H	0.0028	0.184	21.07	0.123
I	0.0058	0.507	129.21	4.998
J	0.0032	0.191	56.18	0.760
K	0.0018	0.033	17.98	0.529
L	0.0024	0.139	26.40	0.588
M	0.0019	0.078	16.29	0.314
N	0.0021	0.078	23.03	0.539
O	0.0022	0.155	17.98	0.745
P	0.0122	1.058	43.31	1.333

evaluated in 5 levels as +2 (very strong in flowing, rhythmical, blowy, etc.), +1 (strong), 0 (average), −1 (weak), and −2 (very weak). Positive side is supposed to have good influence on the appearance of moving flared skirts. Examples of subjective evaluation terms are shown in Fig. 1.

Subjective evaluation was carried out 3 times with a week interval. The agreed results with significance level of 10 % was used for further calculation.

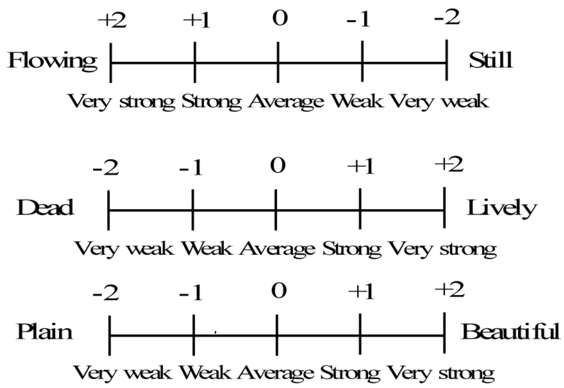

Fig. 1 Examples of evaluation terms.

3. Calculation of Various Drape Coefficients

3.1 Conventional static drape coefficient

Static drape coefficient of fabrics; D_s, and node number; n, are calculated from following equations [7]:

$$D_s = \frac{4a^2 + 2b^2 + 2a_m^2 + b_m^2 - 4R_0^2}{12R_0^2} \quad (1)$$

$$n = 12.797 - 269.9\sqrt[3]{\frac{B}{W}} + 38060\frac{B}{W} - 2.67\frac{G}{W} + 13.03\sqrt{\frac{2HG}{W}} \quad (2)$$

Where, R_0; the radius of circular supporting stand (= 63.5 mm), a; a constant showing total size of two-dimensionally projected area (mm), b; a constant showing height of cosine wave of two-dimensionally projected shape (mm), and a_m, b_m; constants showing anisotropy of fabrics. These constants are obtained from the basic mechanical parameters measured by KES-system [8] using following equations [9]:

$$a = 35.981 + 1519\sqrt[3]{\frac{B}{W}} - 204300\frac{B}{W} + 23.27\sqrt[3]{\frac{G}{W}} + 0.0178G \quad (3)$$

$$b = 29.834 - 1.945n - 0.0188G - 91.84\frac{2HG}{W} \quad (4)$$

$$a_m = 9063\left(\frac{B_1 - B_2}{W}\right)^{\frac{2}{3}}, \quad b_m = 6224\left(\frac{B_1 - B_2}{W}\right)^{\frac{2}{3}} \quad (5)$$

Where, B; bending rigidity (mN·m^2/m), G; shearing stiffness (N/m/rad), 2HG; hysteresis in shearing force at 0.0087 radian (N/m), W; fabric weight (g/m^2), and B_1, B_2; bending rigidity in warp and weft direction, respectively.

3.2 Dynamic drape coefficient

Changes of drape coefficient of fabrics with revolving speed were investigated precisely and following dynamic drape coefficients were defined by Yang and Matsudaira [10-12].

The revolving drape increase coefficient; D_r, was defined as the slope of the graph when the revolving drape coefficient is plotted against rpm, measured in 50-130 rpm range. If the coefficient is larger, the ratio of drape increase coefficient with revolution speed becomes larger. The regression equation for the coefficient is derived as follows:

$$D_r = 0.792 + 2.374\sqrt{\frac{2HG}{W}} - 0.6305\sqrt[3]{\frac{G}{W}} - 6.762\sqrt[3]{\frac{B}{W}} - 2.673\frac{2HG}{W} + 0.0005W \quad (6)$$

On the other hand, if the revolution speed became larger than 180 rpm, the drape coefficient did not increase at all with the revolution speed. Therefore, the revolving drape coefficient at 200 rpm; D_{200}, was defined as saturated drape coefficient at rapid revolution. The regression equation for the coefficient is derived as follows:

$$D_{200} = 61.475 - 37.02\frac{G}{W} + 0.1411G + 40.88\sqrt[3]{\frac{G}{W}} + 0.049W + 436.8\frac{2HB}{W} \quad (7)$$

Where, 2HB is hysteresis in bending moment at 0.5 cm^{-1} (mN·m/m).

The dynamic drape coefficient at swinging motion; D_d, was considered to simulate the human waist motion at walking. The projected area of fabric increased with rotated angle and reached to the maximum area before the set angle, that is the turn-around angle. The area decreased drastically from the maximum area to the minimum area at this angle. Therefore, the difference of projected area at turn-around angle could be a parameter of dynamic drape behavior of fabrics. The dynamic drape coefficient of fabrics at swinging motion is defined as the change of projected area at turn-around angle as follows:

$$D_d = \frac{(S_{Max} - S_{Min})}{\pi R_1^2 - \pi R_0^2} x100(\%) \quad (8)$$

Where, D_d; dynamic drape coefficient at swinging motion, S_{Max}; maximum projected area at the turn-around angle, S_{Min}; minimum projected area at the turn-around angle, R_0; radius of the circular supporting stand (= 63.5 mm), R_1; radius of the fabric sample (= $2R_0$ = 127 mm).

D_d, at the conditions of angular velocity 9.42 rad/s and turn-around angle π rad, is calculated from following equation:

$$D_d = 90.217 + 0.1183W - 720.7\sqrt[3]{\frac{B}{W}} - 41.1\sqrt[3]{\frac{G}{W}} \quad (9)$$

3.3 Index of drape fluidity

Tandon and Matsudaira [13] defined an *Index of drape fluidity*, I, as the ratio of dynamic drapability to static drapability, and is calculated as shown below using the various dynamic drape coefficients:

$$I_r = D_r/D_s \quad (10)$$

$$I_{200} = D_{200}/D_s \quad (11)$$

$$I_d = D_d/D_s \quad (12)$$

I_r is called an index of revolving drape fluidity, I_{200} is an index of saturated drape fluidity, and I_d is an index of dynamic drape fluidity. Higher the value of a particular index of drape fluidity, greater the level of soft and fluid drape. The degree to which the individual index of drape fluidity distinguishes or disperses one fabric from the other can be measured by the coefficient of variation, *CV* %. The higher the *CV* % the greater the dispersion of drape fluidity within a fabric group, or between fabric groups. They showed that the *CV* % values of I_r, I_{200} and I_d were significantly greater than the corresponding values of D_r, D_{200} and D_d and were, therefore, better able to discriminate between the fabrics with respect to their dynamic drapability. They showed the values of the various indices of drape fluidity for the various fabric groups and concluded the revolving drape index, I_r is largest, followed by the dynamic drape index, I_d.

4. Results and Discussion

Subjective raw score data for moving flared skirts obtained by SD method was used for calculation of the multiple regression.

Table 3 Agreed Number of Evaluators.

Item	1st Trial (Total:20)	2nd (23)	3rd (18)
Flowing	20	23	18
Rhythmical	20	20	18
Blowy	18	15	13
Airy	18	21	14
Flexible	20	23	17
Graceful	20	20	15
Lively	20	20	17
Dynamic	15	14	12
Beautiful	18	17	14

Number of agreed evaluators differed with each evaluation terms. The agreed number of panels with significance level of 10 % is shown in Table 3. Averaged values of 3 trial evaluations were used for the regression.

Subjective data were regressed with various drape coefficients; D_s, n, D_r, D_{200}, D_d, I_r, I_{200} and I_d. Popular calculation software; Excel Multivariate Analysis by Esumi Co., Ver. 5 (2010) was used by the stepwise regression analysis with adequate F-in and F-out values of 2.0 [14].

The prediction equation obtained calculates a value (primarily from −2 to +2) that will result when the objective parameter values of drape coefficients are known. The idea is to have an equation that is accurate so that one can predict the movement of the fabric once it is made into a bias-cut four-gore skirt. The equation is as follows:

$$Y = C_0 + \sum C_i \frac{(X_i - M_i)}{\sigma_i} \quad (13)$$

Where Y is the evaluation terms of a flared skirt evaluated objectively, C_0 is the average value of each of the terms obtained subjectively (constant), C_i is the regression coefficient of drape coefficients obtained by the multiple regression analysis, X_i is the calculated value of fabric drape coefficient, M_i is the mean value of the fabric drape coefficient, σ_i is the standard deviation of the fabric drape coefficient.

The results of the regression coefficients taken in the prediction equations are shown in Table 4–12 with those of means and standard deviation of the drape coefficient. Multiple correlation coefficients R are also shown in these tables. A triple asterisk means 0.1 % significance level by analysis of variance, and a double asterisk means 1 %.

The results in Table 4 establish that relationship between a large flowing movement score of flared skirt is high with a fabric having smaller D_s (conventional static drape coefficient), smaller D_d (dynamic drape coefficient) and smaller n (node number).

The regression coefficients taken in the prediction equation of rhythmical movement are D_s, n, D_{200} (saturated drape coefficient) and I_d, (dynamic drape fluidity) as shown in Table 5. Rhythmical

Table 4 Coefficients of Parameters for Prediction of "Flowing" Movement of Flared Skirts Objectively; C_0 = 0.3801, R = 0.910***

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.8348	38.80	13.60
D_d	%	−1.2058	55.03	12.91
n	—	−1.1235	5.765	1.165

Table 5 Coefficients of Parameters for Prediction of "Rhythmical" Movement of Flared Skirts Objectively; C_0 = 0.1060, R = 0.927***

Parameter	unit	C_i	M_i	σ_i
D_s	%	−1.9550	38.80	13.60
n	—	−0.7030	5.7651	1.165
D_{200}	%	−0.5205	86.44	5.526
I_d	—	−0.4513	1.669	0.7921

Table 6 Coefficients of Parameters for Prediction of "Blowy" Movement of Flared Skirts Objectively; C_0 = 0.0497, R = 0.858***

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.0900	38.80	13.60
D_d	%	−0.9591	55.03	12.91
n	—	−0.7718	5.765	1.165

Table 7 Coefficients of Parameters for Prediction of "Airy" Movement of Flared Skirts Objectively; C_0 = 0.4687, R = 0.871**

Parameter	unit	C_i	M_i	σ_i
D_s	%	−1.5936	38.80	13.60
n	—	−0.5978	5.765	1.165
D_r	%/ rpm	−0.4857	0.3856	0.0995
D_{200}	%	−0.3119	86.44	5.526

movement score increases with decreasing these parameters.

The results in Table 6 establish that blowy movement is dominated by D_s, D_d and n. This combination is quite similar to that of flowing movement. The same parameters are taken in the prediction equation with the same tendency.

The results in Table 7 establish that airy movement is most likely to occur when the fabric shows small D_s, small n, small D_r (revolving drape increase coefficient), and small D_{200}. The score of airy movement becomes larger with lower values of these parameters.

Flexible movement of a flared skirt is evaluated as larger by smaller values of D_s, n, D_{200} and Id as shown in Table 8. The combination of these parameters is quite similar to that of

Table 8 Coefficients of Parameters for Prediction of "Flexible" Movement of Flared Skirts Objectively; $C_0 = 0.5250$, $R = 0.940^{***}$

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.5112	38.80	13.60
n	—	−1.0549	5.765	1.165
D_{200}	%	−0.6405	86.44	5.526
I_d	—	−0.5474	1.669	0.7921

Table 9 Coefficients of Parameters for Prediction of "Graceful" Movement of Flared Skirts Objectively; $C_0 = 0.4941$, $R = 0.933^{***}$

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.3510	38.80	13.60
n	—	−1.0441	5.765	1.165
D_d	%	−0.7023	55.03	12.91
D_{200}	%	−0.2701	86.44	5.526

Table 10 Coefficients of Parameters for Prediction of "Lively" Movement of Flared Skirts Objectively; $C_0 = 0.3356$, $R = 0.918^{***}$

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.2118	38.80	13.60
D_d	%	−0.9468	55.03	12.91
n	—	−0.8476	5.765	1.165

Table 11 Coefficients of Parameters for Prediction of "Dynamic" Movement of Flared Skirts Objectively; $C_0 = -0.4342$, $R = 0.901^{***}$

Parameter	unit	C_i	M_i	σ_i
D_s	%	1.9763	38.80	13.60
n	—	0.9069	5.765	1.165
D_{200}	%	0.5061	86.44	5.526
I_d	—	0.4551	1.669	0.7921

Table 12 Coefficients of Parameters for Prediction of "Beautiful" Movement of Flared Skirts Objectively; $C_0 = 0.5611$, $R = 0.938^{***}$

Parameter	unit	C_i	M_i	σ_i
D_s	%	−2.6275	38.80	13.60
D_d	%	−1.0968	55.03	12.91
n	—	−1.0901	5.765	1.165

rhythmical movement.

Graceful movement score becomes larger with larger value of D_s, n, D_d and D_{200} as shown in Table 9.

Lively movement of flared skirt is evaluated from D_s, D_d, and n as shown in Table 10. The combination of the prediction equation is as same as those of flowing and blowy movement. This means that these 3 terms are evaluated similarly by subjective evaluation.

Results of dynamic movement are shown in Table 11. The combination of drape parameters are D_s, n, D_{200} and Id, and this is the same as rhythmical and flexible movement. However, all the signs of coefficient are the opposite. This means that the effect of these parameters on dynamic movement is just the opposite of rhythmical and flexible movement.

Beautiful movement is considered to be total aesthetic appearance term and is calculated from the combination of D_s, D_d, and n as shown in Table 12. The score of beautiful movement increases with smaller values of these parameters. This combination is the same as those of flowing, blowy and lively. If we compare the contribution of each parameter on the subjective term, the contribution ratio of D_s, D_d and n are as follows. For flowing movement; 55 %, 24 % and 22 %. For blowy movement, 55 %, 25 % and 20 %. For lively movement; 55 %, 24 % and 22 %. For beautiful movement; 55 %, 25 % and 20 %. The absolute values are quite similar with one another. This means that beautiful movement of flared skirt is evaluated similarly with flowing, blowy and lively movement. It is enough to evaluate only beautiful movement. The parameters obtained here; D_s, D_d, n are different with those of former results, only D_d and D_r are selected [2]. Main reason is considered to be the movement of flared skirt. When we used a simulated mannequin, the stand rotated within 30 degree. When we used a walking model, the skirt did not revolve. Therefore, dynamic and revolving drape coefficients are the most effective parameters in the former case and static drape coefficient is the most effective in the latter case.

If you measure basic mechanical parameters of a fabric sized 20 cm × 20 cm by KES-system, you can calculate various drape coefficients by the equations from (1) to (12). Then you can calculate appearance terms of flared skirts by equation (13) objectively.

5. Inspection of the Prediction Equations

To prove the validity of prediction equations developed above, these equations are applied to other samples as shown in Table 13 and mechanical parameters are shown in Table 14 [6]. Skirts are made as similar manner as shown in 2.1 and subjective evaluation test were carried out by 24 female students of Ehime university aged from 19 to 22. Appearance of flared skirts worn by a model is evaluated by SD method as similar way as shown in 2.2 for the same 9 evaluation terms. The relationship between subjective and predicted values are shown in Fig. 2-10.

Table 13 Samples Used to Inspect the Reliability of Predicted Equations.

Sample No.	Fabric Name	Density (/m)		Count (tex)		Twist (/m)		Weight (g/m²)	Thickness* (mm)
		Warp	Weft	Warp	Weft	Warp	Weft		
1	Wool a	2900	2200	34.5	34.5	1150	1550	202.9	0.839
2	Rayon a	3800	2800	33.5	33.5	1800	2100	241.0	0.777
3	Cotton	7000	4100	7.3	7.3	1580	1360	80.7	0.563
4	Wool b	2500	2800	32.3	32.3	520	780	274.1	0.830
5	Cotton b	4000	2800	19.1	19.1	1050	1100	162.5	0.592
6	Polyester a	2900	2300	32.5	35.7	3360	2040	215.6	1.290
7	Cotton c	6000	3800	8.9	8.9	1240	1440	97.7	0.580
8	Wool c	2700	2500	28.7	32.7	960	1040	206.4	0.758
9	Polyester b	3800	3700	10.1	12.1	4100	4000	111.3	0.510

*Thickness is measured at the pressure of 49 Pa.

Table 14 Mechanical Parameters of Samples Used to Inspect the Reliability of Predicted Equations.

Sample No.	B (mN·m²/m)	2HB (mN·m/m)	G (N/m/rad)	2HG (N/m)
1	0.0093	0.2822	26.40	0.7546
2	0.0071	0.2528	16.85	0.4312
3	0.0042	0.1891	17.98	0.441
4	0.0130	0.4008	33.71	0.6566
5	0.0101	0.7370	79.78	2.2344
6	0.0073	0.2009	21.35	0.5684
7	0.0049	0.4812	34.83	1.764
8	0.0044	0.1646	15.73	0.2058
9	0.0014	0.0764	17.42	0.4802

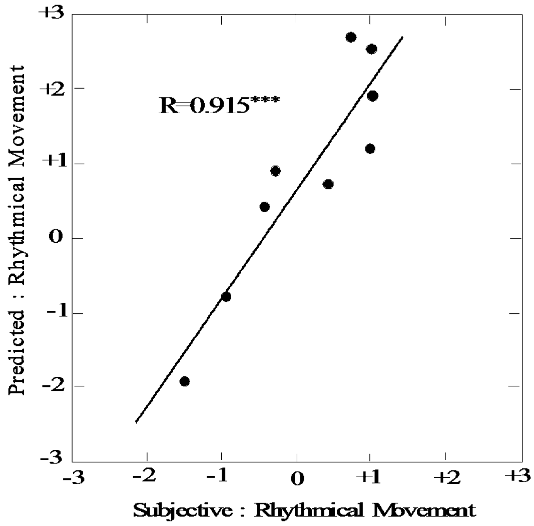

Fig. 3 Relationship of rhythmical movement.

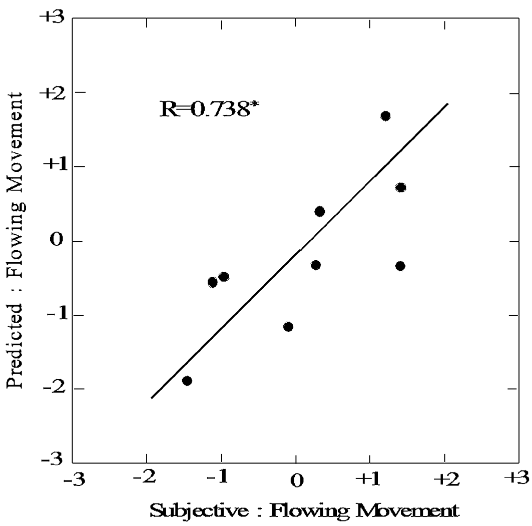

Fig. 2 Relationship of flowing movement.

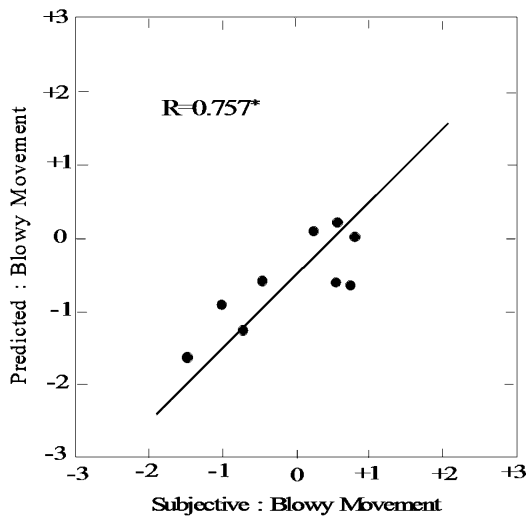

Fig. 4 Relationship of blowy movement.

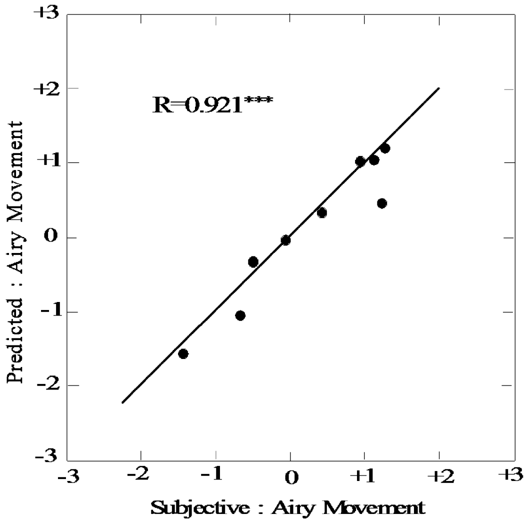

Fig. 5　Relationship of airy movement.

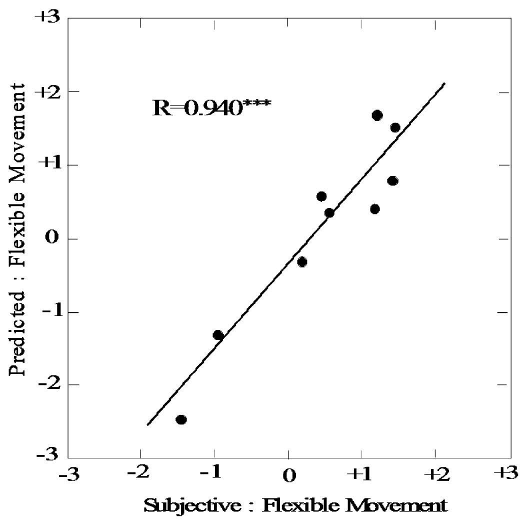

Fig. 6　Relationship of flexible movement.

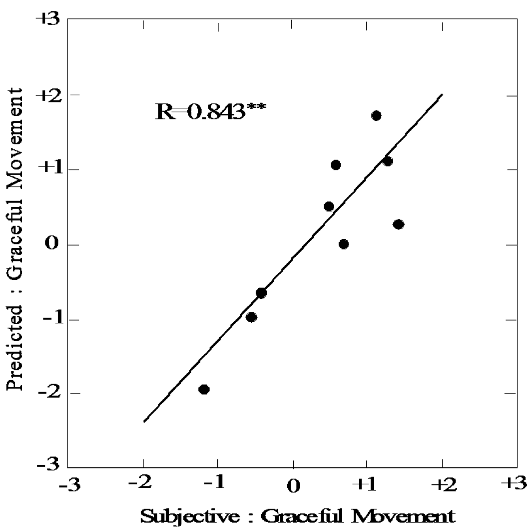

Fig. 7　Relationship of graceful movement.

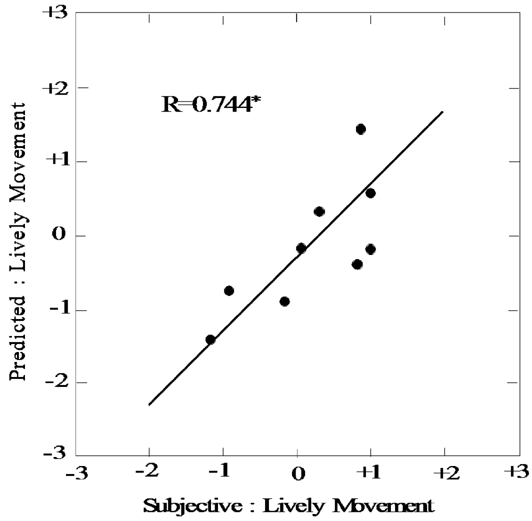

Fig. 8　Relationship of lively movement.

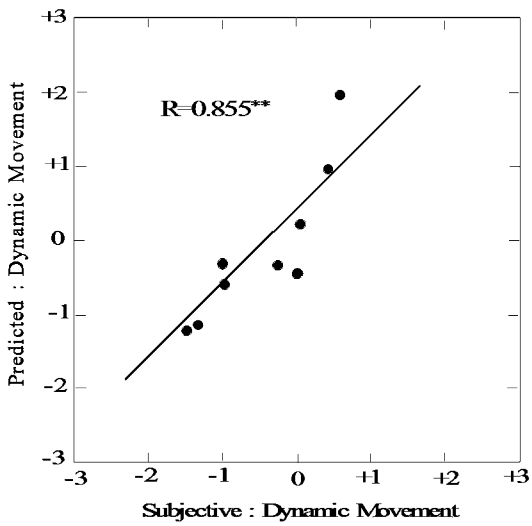

Fig. 9　Relationship of dynamic movement.

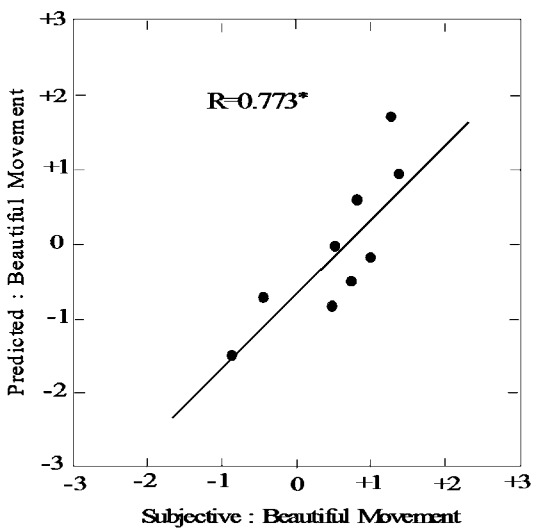

Fig. 10　Relationship of beautiful movement.

Agreement is very high (0.1 % significance level) for the evaluation terms “rhythmical”, “airy” and “flexible” movement, however, it is not so high (5 % significance level) for “flowing”, “blowy”, “lively” and “beautiful” movement. However, we can conclude that the agreement between subjective and objective data is well for all the evaluation terms of moving flared skirts. Therefore, you can estimate reliable values of appearance of flared skirts by the prediction equations derived here.

In the point of evaluation terms, it is concluded that “beautiful” movement is the same as “flowing”, “blowy” and “lively” movements. “Rhythmical” movement can represent “flexible” movement. “Dynamic” movement has the opposite appearance to both “rhythmical” and “flexible” movements. Therefore only 4 terms such as “rhythmical”, “airy”, “graceful” and “beautiful” movements are sufficient to evaluate swinging flared skirts.

6. Conclusions

Prediction equations of appearance of flared skirts worn by a model are derived from various drape coefficients of fabrics which are calculated from the basic mechanical parameters measured by KES-system. Following conclusions were obtained.

(1) “Flowing”, “rhythmical”, “blowy”, “airy”, “flexible”, “graceful”, “lively”, “dynamic” and “beautiful” movement of flared skirts are evaluated objectively from a combination of drape coefficients.

(2) “Beautiful” movement of flared skirts is evaluated from similar drape parameters with “flowing”, “blowy” and “lively” movements.

(3) “Dynamic” movement is evaluated as just the opposite of “rhythmical” and “flexible” movements.

(4) Only 4 terms such as “rhythmical”, “airy”, “graceful” and “beautiful” movements are enough to evaluate the appearance of swinging flared skirts.

(5) Conventional static drape coefficient (D_s) is the most dominant parameter which can decide appearance of moving flared skirts.

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