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JOINT MOVEMENT IN PRECAST CONCRETE PANEL CLADDING

by K.K. Karpati and P.J. Sereda

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LE MOUVEMENT DES JOINTS DANS UN PAREMENT DE PANNEAUX DE BETON PREFABRIQUE

SOMMAIRE

On mesure les mouvements de joints entre des panneaux de béton préfabriqué dans un grand immeuble. Les mouvements sont mis en corrélation avec les changements de température de l'air et on en fait une évaluation statistique. Un coefficient de mouvement expérimental est calculé à l'aide de l'inclinaison de la ligne de régression et des dimensions des panneaux, et on le compare au coefficient linéaire publié de la dilatation thermique du béton.

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Joint Movement in Precast Concrete Panel Cladding

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ABSTRACT: Joint movements between precast concrete panels were measured on a high-rise building. The movements were correlated to air temperature changes and were statistically evaluated. An experimental coefficient of movement was calculated from the slope of the regression line and the dimension of the panels and was compared to the published linear coefficient of thermal expansion of concrete.

KEY WORDS: displacement, construction joints, concretes, joint movement, building joint movement, movements in buildings

It is common practice to use precast concrete panels as the exterior cladding on buildings. These panels are made to various dimensions, to conform with the design module of the building, and to facilitate ease of fabrication, handling, and attachment to the structure. This results in a wall made of discrete units with numerous joints which must accommodate thermal movements and at the same time be sealed to form an integral wall that will exclude rain and serve as an acceptable aesthetic facade to the building.

Clearly the design of the joints between panels is important in the satisfactory performance of the exterior cladding. This study of joint movement in an actual building was prompted by the occurrence of sealant failure in such walls and the lack of available information on the subject.

The study was carried out on precast concrete panels on a building reported to be undergoing severe water leakage. The aim was to determine if the failure of sealed joints was due to joint movement in excess of that calculated from the thermal coefficient of linear expansion of the concrete; that is, the coefficient (with an added safety factor) that is generally used in the design of such walls.

Experimental

Joint movements between precast concrete panels were measured on the penthouse of a high-rise building in downtown Ottawa. The penthouse was chosen because it was so easy to measure, the panels being the same as on the building itself. Figure 1 shows the penthouse. The panels are 12 by 5 ft (3.6 by 1.5 m) on the bottom row and 14 by 5 ft (4.3 by 1.5 m) on the top row. As can be seen from the picture, the panels have a

FIG. 1—The penthouse where joint movement measurements were taken.

scalloped shape that increases the total thickness from 3 to 6 in. (76 to 152 mm) at the thickest section.

On the back of the concrete panels there is a 2-in. (51-mm) thick layer of rigid insulation. The insulation is separated from the inside 6-in. (152-mm) concrete block wall by a 6-in. wide cavity. (The location of the insulation in the wall should have been on the other side of the cavity to be more effective.) The panels are fastened to the cross members (spandrel beams) with angle brackets at both top and bottom.

Figure 2 illustrates the plan of the penthouse. The joints accessible from the rooftop are numbered from 0 to 39. A total of twelve joints were measured, and these are marked with a circle on the plan. Most joints selected for measurement showed five to ten failure points of the sealant, although Joints 6 and 39, where the sealant was not cracked, were also included. Joint 0 showed failure only at a corner. Most measuring points were located close to corner columns where one can expect less sagging of the spandrels to which the panels were attached and, therefore, less distortion in the parallelism of the joint. The location of the measuring points included joints exposed to all four cardinal directions. Two of the joints observed were horizontal and ten vertical.

To measure the joint movement a gage was made based on the design of a similar gage developed by the British Building Research Establishment. This gage records the maximum and minimum joint widths during selected time intervals. The maximum and minimum temperature readings were observed for the same periods using a Taylor maximum-minimum

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FIG. 2—Plan of the penthouse.

thermometer. This enabled the joint movement to be evaluated as a function of temperature changes.

Based on previous experiences [1] with joint movement recordings, readings were taken at two-week intervals. This frequency of reading provides a sufficient amount of data for accurate statistical analysis.

Description of the Joint Movement Gage

The joint movement gage is schematically illustrated in Fig. 3. It consists of a stainless steel block (a) containing two pistons which are equipped with a special adjustable friction device (b). The block is rigidly attached to one side of the joint by means of an extension bar and a wall plug (c). On the other side of the joint a reference plug (d) is attached to the wall, carrying a spherical head (e). At the start of an experiment the pistons are pushed in until they touch the spherical head. As the joint opens after a temperature drop, the spherical head pushes the piston, marked I, ahead of it. When the joint movement changes direction and the joint closes,

FIG. 3—Cross section of joint movement gage bridging the joint.

Piston I is left behind and Piston II is pushed ahead of the sphere. In subsequent daily cycles the pistons are pushed further out, provided the joint width extremes exceed the previously registered ones. At the end of the chosen two-week period the pistons are in the positions corresponding to the maximum and to the minimum joint width occurring during this period.

The position of the pistons is measured at the end of each period with a depth gage at the points indicated by double arrows in Fig. 3. The depth gage measures the distance between the flat surface of the piston and the end face of the stainless steel block. The reading accuracy is ± 0.0005 in. (0.0127 mm). The depth measurement indicated by A in Fig. 3 gives the maximum, while B is the minimum joint width occurring during the period observed.

To increase the number of data for the same number of field trips, after the depths of the cylinders were read the pistons were pushed back until they touched the spherical head and the depths were read again at these reset positions. When the joint width is plotted versus the corresponding temperature, the reset values taken at position A fall on the same plotted line as the A readings related to the maximum joint width achieved in the time period just passed. The same is true for the B readings. The plots of maximum joint width versus temperature and that of minimum joint width versus temperature give two lines with opposite slope. These two lines represent the same result: that the joint movement correlates to temperature and should be combined so that all the readings can be statistically evaluated together as a unit, greatly increasing the accuracy. The depth reading B can be expressed in terms of A by a simple calculation. If both cylinders are pushed in until they touch the sphere (A_{set} , B_{set}), then the following equation can be written:

$$A_{set} + B_{set} + P = L$$

where P is the combined length of the cylinders and the spherical head and L is the total length of the casing. P and L are constants of the gage and, therefore, for any reading of B a corresponding A reading (A_c) can be calculated from the above

equation. The direct A readings and the calculated A_c readings fall on the same plotted line.

A FORTRAN IV program was written for an IBM 360 computer to provide the necessary statistical calculations, and a tape for plotting the data and the best fitting lines was obtained as a result of the calculations. The plottings were done on an EAI 430 Data-plotter.

Discussion

Readings were taken during a period of a full year (starting in February 1969) to include the coldest and the warmest part of a year and, therefore, to record the maximum and the minimum joint widths that occurred.

The data were subjected to a statistical analysis in which the depth gage readings, which are in fact the relative joint positions, in inches, at a given time, were correlated to the appropriate temperature readings. In Table 1 it can be seen that two of the

TABLE 1—Statistics indicating joint movements.

Joint	Direction	r	n	b
0	vertical	0.74	114	0.00022
5	vertical	0.90	115	0.00032
7	vertical	0.79	117	0.00024
11	horizontal	0.85	108	0.00047
16	vertical	0.07	116	0.00002
25	vertical	0.89	117	0.00041
29	vertical	0.91	114	0.00051
34	horizontal	0.90	101	0.00054
39	vertical	0.51	117	0.00009

r = correlation coefficient

n = number of pairs of observations

b = slope of regression line

twelve joints investigated did not move with the temperature changes during a period of observation of a full year. These are Joints 16 and 39, both vertical joints at a corner column, the former on the east and the latter on the west elevation. The criterion that establishes this lack of movement with temperature change is the value obtained for the correlation coefficients given in Table 1. The coefficients are 0.07 and 0.51 for Joints 16 and 39, respectively. Although the latter shows a much higher correlation coefficient than the former, it is still much too low to be considered significant. The table also gives the number of observations (n) and the slope of the regression lines (b). The latter, being the joint movement in inches per degree Fahrenheit change, also indicates if the joint does not move. Indeed, the values obtained, 0.00002 and 0.00009 in./°F, are significantly lower than the mean slope obtained for the other joints, that is, 0.00036 in./°F.

The total number of joints investigated was twelve, of which seven showed appreciable movement. All joint movement data were subjected to a statistical analysis after about two months of observation, and the data collection was stopped in three cases, Joints 3, 6, and 33, when the correlation coefficient was found to be very low. Although the coefficient for Joints 16 and 39 was low as well during the initial observation period, readings were taken for the full year to see if the increased number of observations would improve the correlation. The

yearly data merely confirmed the lack of movement at those joints.

A representative plot obtained with the data collected on a moving joint is shown in Fig. 4. It illustrates Joint 11 that had a correlation coefficient equivalent to the mean of the various joints that showed movement (see Table 1). On the vertical axis the depth gage readings are given in inches and centimeters and on the horizontal one the temperature readings in degrees Fahrenheit and Celsius. The maximum temperature readings related to the minimum joint width readings are illustrated by "x" symbols, the minimum temperature with circles, and the reset temperature readings with "+" symbols. The regression lines are drawn as a continuous line for maximum temperature, as a dashed line for minimum, and as dotted line for the reset temperature data. The plot shows that there is a fair amount of scatter, which can be attributed partly to the comparatively low accuracy of the readings together with human errors and partly to causes of movement other than temperature variations, such as moisture content changes.

Table 2 presents the results of the detailed statistical analysis obtained with joints that moved with temperature changes. For each joint the maximum, minimum, and reset readings, correlated to the corresponding depth readings, are analyzed separately as well as together. The confidence limits of the slopes are calculated as follows [1]:

$$b \pm ts_b$$

where b is the slope, t is Student's test, and

$$s_b = s_y / \sqrt{\sum x_i^2 - (\sum x_i)^2 / n} \quad (2)$$

where s_y is the standard error of the data, x_i is the i th reading, and n is the number of pairs of data.

The results of the analysis done separately on the various types of temperature readings show that the maximum temperature data have a tendency to give a greater slope (movement per degree Fahrenheit change) than the minimum temperature data, with the reset temperature results intermediate. In the case of Joints 5 and 25, the slopes are distinctly different; the bands delineated by the 90% confidence limits do not overlap when comparing maximum and minimum temperature readings. For the other joints in Table 2, with the exception of Joint 7, there is overlapping of the 90% confidence limits. Therefore, they have to be considered identical within the errors of the experiment. Nevertheless when all the slopes of all the joints are compared, there is a definite trend of higher values for the maximum than for the minimum temperature data, with the reset data taking an intermediate position. For Joint 7 the correlation coefficient is so low for the maximum temperature data that this group has to be considered erroneous and dropped from the analysis. The slope of reset and minimum temperature data obtained for the same joint confirms, however, the trend found for the other joints.

This trend of the slopes means in terms of joint behavior that the joint responds with a relatively larger movement to temperature variations at higher temperatures. A possible explanation of this phenomenon is that at decreasing temperatures the importance of the moisture content of the panel increases. A higher moisture content, resulting from higher relative humidity

FIG. 4—Maximum-minimum gage at horizontal joint 11.

in the air at lower temperatures, will produce a swelling opposing the shrinkage induced by the decreasing temperature.

When the data for different temperatures are analyzed together, the correlation coefficient averages out the slight variations of the separate ones. Hence the combined data provide a suitable basis for comparing the behavior of different joints. The results of the calculation of Eq 1 ($\pm t_{s_b}$ as given in Table 2) demonstrate that the slopes of the combined data always differ significantly from zero using the t test at the 90% confidence level. Therefore, joint movement correlates with temperature change. For vertical joints the slopes range from 0.00022 ± 0.00003 to 0.00051 ± 0.00004 in./°F.

From the above slope and the length of the panel contributing to the movement an experimental coefficient of linear expansion can be calculated. The length contributing to the movement of vertical joints, if the joint is between two panels each 5 ft (1.5 m) wide, is 5 ft, since they both move, theoretically, from the center outwards. However, if the joint is at a corner, the corner panel has only a 1½-ft (0.46-m) width, of which ¾ ft (0.23 m) will contribute to the movement and, on the other side of the joint, 2½ ft (0.76 m) will be contributed by the other panel, giving a total of 3¼ ft (0.99 m).

Table 3 presents the experimental coefficients obtained by dividing the value obtained for the slope by the width of the panel. For vertical joints, they range from 6.4×10^{-5} to 10.2×10^{-5} in./°F/ft where the 90% confidence limits of the former value are 5.8 and 7.0×10^{-5} in./°F/ft, while those for the latter coefficient are 9.4 and 11.0×10^{-5} in./°F/ft. The 90% confidence limit lies within a fairly narrow range of values, which, when compared to the linear coefficient of thermal expansion of concrete of 8×10^{-5} in./°F/ft, indicates that one of the joints (No. 29) moved more than expected, based on the published coefficient. Another joint (No. 25) showed about as much movement as predicted from the published co-

efficient. Both these joints had a southern exposure. The joints with 6.4 to 7.4×10^{-5} in./°F/ft experimental coefficients were on the northern and western sides.

Two of the seven joints were horizontal, and the results of their movement are summarized at the bottom part of Table 2. The movement at the horizontal joints, in absolute value, is in the same order as that of the vertical joints but when the experimental coefficient of the joint movement is calculated, the coefficients are half of those for the vertical joints. This indicates that the panels are restrained in their movements in the vertical direction along the 13-ft (4-m) lengths (average) but not along the shorter 5-ft (1.5-m) widths.

Conclusion

It was established through statistical analysis that seven joints of the twelve observed on a concrete panel wall serving as cladding showed joint movements that correlated well with the air temperature changes measured at the joint. The remaining five joints showed some movement but only within experimental error and, therefore, cannot be considered as moving with temperature variations. The slope of the regression lines obtained for the joint movements versus temperature readings is the movement in inches per degree Fahrenheit change and is a characteristic of each joint. From the slope and the dimensions of the panels forming the joint an experimental joint movement coefficient was calculated. A comparison of these experimental coefficients with the published linear coefficient of thermal expansion of concrete demonstrated that most of those vertical joints that moved underwent movement equal to or less than that predicted by the published coefficient. In one case, the movement was about 20% greater. The two horizontal joints, however, moved only half of what was predicted. The possible reason for the variations is the method of fastening the panels

TABLE 2—Statistical analysis of joint movement versus temperature change.

	n	r	b	+ ts _b	s _y
Vertical Joint 0					
Max temp	38	0.7709	0.00020	0.00005	0.00382
Min temp	38	0.6822	0.00020	0.00006	0.00523
Reset temp	38	0.5997	0.00022	0.00008	0.00733
Mx + Mn + Rst temp	114	0.7423	0.00022	0.00003	0.00565
Vertical Joint 5					
Max temp	38	0.8855	0.00033	0.00005	0.00410
Min temp	39	0.8521	0.00023	0.00004	0.00351
Reset temp	38	0.8454	0.00029	0.00005	0.00460
Mx + Mn + Rst temp	115	0.9024	0.00032	0.00002	0.00444
Vertical Joint 7					
Max temp	39	0.4723	0.00010	0.00006	0.00504
Min temp	39	0.7524	0.00021	0.00005	0.00410
Reset temp	39	0.7851	0.00024	0.00005	0.00438
Mx + Mn + Rst temp	117	0.7950	0.00024	0.00003	0.00532
Vertical Joint 25					
Max temp	39	0.8663	0.00049	0.00008	0.00540
Min temp	39	0.8847	0.00032	0.00005	0.00414
Reset temp	39	0.9178	0.00036	0.00004	0.00331
Mx + Mn + Rst temp	117	0.8894	0.00041	0.00003	0.00528
Vertical Joint 29					
Max temp	38	0.8417	0.00053	0.00010	0.00660
Min temp	38	0.9440	0.00043	0.00004	0.00364
Reset temp	38	0.8956	0.00047	0.00007	0.00507
Mx + Mn + Rst temp	114	0.9053	0.00051	0.00004	0.00590
Horizontal Joint 11					
Max temp	36	0.7229	0.00043	0.00012	0.01045
Min temp	36	0.8956	0.00055	0.00008	0.00579
Reset temp	36	0.8790	0.00056	0.00009	0.00702
Mx + Mn + Rst temp	108	0.8523	0.00047	0.00005	0.00823
Horizontal Joint 34					
Max temp	34	0.9031	0.00059	0.00008	0.00576
Min temp	34	0.8527	0.00052	0.00010	0.00751
Reset temp	33	0.8540	0.00055	0.00010	0.00795
Mx + Mn + Rst temp	101	0.8967	0.00054	0.00004	0.00707

n = number of pairs of observations

r = correlation coefficient

b = slope

t = Student's *t* tests_b = standard error of the slopes_y = standard error of the data

TABLE 3—Experimental movement coefficients.

Joint	b	Location	Length, ft	(m)	in./°F/ft	1/°F	1/°C
Vertical Joints							
0	0.00022	corner	3¼	(0.99)	6.8 × 10 ⁻⁵	5.6 × 10 ⁻⁶	10.2 × 10 ⁻⁶
5	0.00032	...	5	(1.5)	6.4 × 10 ⁻⁵	5.3 × 10 ⁻⁶	9.6 × 10 ⁻⁶
7	0.00024	corner	3¼	(0.99)	7.4 × 10 ⁻⁵	6.2 × 10 ⁻⁶	11.1 × 10 ⁻⁶
25	0.00041	...	5	(1.5)	8.2 × 10 ⁻⁵	6.8 × 10 ⁻⁶	12.3 × 10 ⁻⁶
29	0.00051	...	5	(1.5)	10.2 × 10 ⁻⁵	8.5 × 10 ⁻⁶	15.3 × 10 ⁻⁶
Horizontal Joints							
11	0.00047	...	13	(3.96)	3.6 × 10 ⁻⁵	3.6 × 10 ⁻⁶	5.4 × 10 ⁻⁶
34	0.00054	corner	13	(3.96)	4.2 × 10 ⁻⁵	3.5 × 10 ⁻⁶	6.2 × 10 ⁻⁶

b = slope

that allowed horizontal movement but partly restrained vertical movement. Similarly, the lack of movement at some vertical

joints can be attributed to the panels yielding along one line of attachment points more than along another.

The necessary joint width for the 5-ft (1.5-m) wide panels can be calculated as described in Ref 2 from the movement anticipated, $5 \text{ ft} \times 125^\circ\text{F} (52^\circ\text{C}) \times 8 \times 10^{-5} \text{ in.}/^\circ\text{F/ft} = 0.05 \text{ in.} (1.27 \text{ mm})$, and from the movement capability of a sealant, where 125 deg is the estimated yearly temperature change. Assuming the use of a good quality sealant with $\pm 25\%$ movement capability, the width W should be:

$$W_{25} = [0.5 \text{ in.}/(2)(25)](100) = 0.1 \text{ in.}$$

If a sealant of $\pm 5\%$ movement capability were used, the required joint width would be

$$W_5 = [0.05/(2)(5)](100) = 0.5 \text{ in.}$$

The joint widths derived do not include a safety factor and should therefore be increased by 50%, as is standard practice in the industry. The actual width of the observed joints varied between $\frac{1}{2}$ and $\frac{3}{8}$ in. (12.7 and 15.875 mm). When compared to the calculated width it is evident that an upgrading of the movement capability of the sealant used would ensure a fail-free system.

It was observed that the joint movement was relatively larger at increasing temperatures than at decreasing ones. The possible reason is that for decreasing temperatures there is moisture condensation in the pores of the panels that causes expansion which acts to reduce the shrinkage induced by the temperature drop.

Although the two joints that moved most were both on the southern exposure, one cannot draw the conclusion that this would generally be the case because of the small number of joints observed and because there were joints for all of the cardinal exposures that did not move. Further investigation is needed to clarify this point.

This work indicates that prediction of joint movement based on the published coefficient of thermal expansion for concrete should be acceptable because the actual movement is not likely to be greater due to restraints and moisture content increases during the cooling cycle. The exception may occur in the first year of the life of the building when drying shrinkage of concrete panels may be an additional factor.

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