EVALUATION OF THE STRUCTURAL ELEMENTS OF PVC-CONCRETE HOUSES

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Technical Report

Mr. Bernard McNamara
President
Systèmes Digigraph Inc.
1610 rue Eiffel
Boucherville (Québec) J4B 5Y1

YVES PÉLOQUIN
TECHNICAL DEVELOPMENT ADVISOR

INGÉNIEUR
Claude Sauvageau
35853
QUÉBEC

CLAUDE SAUVAGEAU, P. ENG.
TECHNICAL MANAGER
PRODUCTS AND TESTS DEPARTMENT

GINETTE DELISLE, . P. ENG.
DIRECTOR

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CRIQ
CENTRE DE RECHERCHE
INDUSTRIELLE DU QUÉBEC

The tests were conducted between January 10, 1996 and January 27, 1997. The PVC samples were received at the CRIQ on January 16, 1996.
The following persons were involved in the project:

- Claude Sauvageau, P. Eng.,
- Michel Poulin, Tech.,
- Sylvain Benjamin, Tech.,
- Daniel Carrier, Tech.

Total number of pages: 73 including 56 pages in appendix.

The results presented in this report refer only to the products described in this report.

The equiprrient and instrumentation used during this test were verified and/or calibrated. The calibration certificates are retraceable to the National Research Council of Canada (NRC) and/or to the American National Institute of Standards and Technology (NIST) standards and can be provided on request.

CRIQ is registered ISO 9001:1987, certificate no. 167-0075-18. The tests department is also accredited by the National Council of Canada, certificate no. 138.

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1. INTRODUCTION

At the request of Systèmes Digigraph Inc., tests were conducted to check various characteristics of the structural elements used in PVC and concrete houses. The work was carried out in the following stages:

- strength analyses of the concrete;
- concrete and form behaviour tests during pour;
- flame propagation tests on the PVC casing;
- seepage and air infiltration tests;
- behaviour tests during freeze / thaw cycles.

The flame propagation as well as seepage and air infiltration tests were conducted per the Canadian Construction Materials Centre (CCMC) technical manual, number 13126 (revised on 1994/03/01) for plastic housing systems.

2. STRENGTH ANALYSIS

Canadian structural standards and some requirements for Mexico, notably earthquakes and hurricanes, were factored into the test on the mechanical strength of the concrete roof and walls.

Mr. Claude Bellier, an engineer and consultant, conducted the strength analysis of the concrete, the results of which are reported in appendix A. They assume that the concrete alone carries the loads. The PVC profiles are only considered as forms, thus increasing the overall safety factor. The following loads were taken into consideration for houses in Mexico :

- Concrete and roofing selfweight;
- 10 Ib per sq. ft of rain (0.48 kPa);
- 0.2 W factor earthquake;
- 250 km/h winds.

A 0.2 W factor implies that 20% of the total weight of the structure is considered as a shear load due to the horizontal movements caused by an earthquake measuring about 7 or 8 on the Richter scale.

The following loads were factored into houses to be built in Montreal:

- Concrete and roofing selfweight;
- 45 Ib per sq.ft of snow (2.15 kPa).

The results indicate that the components are strong enough for these loads, the concrete alone can carry the indicated loads on one- or two-story houses. Different size wooden or steel beams can be used on the roof depending on the load conditions (Mexico and Montreal). The possible choices are listed in Annex A.

Standard or lightweight concrete may be used. Standard concrete must have a minimum strength of 20 MPa; and, at 28 days, ISO-Mix type lightweight concrete must have a minimum strength of:

- 4 MPa for the walls;
- 6 MPa for roof slabs (weather conditions in Mexico);
- 10 MPa for roof slabs (weather conditions in Montreal).

A steel armour is required only in the following areas :

- Roof beams fastened to the waff by ½inch diameter bolts (M12).
- Lintel above the openings, a 15 M rod sunk in the concrete below the lintel and extending 600 mm on each side of the opening.

3. DESCRIPTION OF THE SAMPLES

The PVC profiles (lot number E005069) required for the installation was delivered to the CRIQ on January 16, 1996 and were used to complete various sections of the wall and roof. With the exception of one 2-mm tongue, the nominal thickness of the PVC profiles was 3 mm. Three types of concrete were used in the pour; the sections obtained are listed in table 1.

As planned, the roof sections were installed during actual construction with supports 1 m apart centre to centre, each with a nominal width of 100 mm and with a roof pitch of 1 in 5. The gap between the bottom of the roof and the centre of the first support measured 0.5 m. The completed roof and wall sections are shown in Photos 1 and 2 respectively.

4. POUR OF CONCRETE

The various completed sections were installed in a room at 40 °C and the concrete was poured on January 30, 1996 under the same conditions. All the elements were left at 40 °C for six days until February 5, 1996 and then left at room temperature in the laboratory. Three types of concrete were used: aerated (contains a high percentage of air); standard 30 MPa concrete and Iso-Mix concrete with beadwall.

Journeaux, Bédard et Ass. Inc. collected samples of concrete to check the characteristics of the concrete used. Standard test procedure dictates that the samples be stored in a water bath. In order to replicate actual operating conditions in which the concrete would not be sprayed with water, the samples were left in the same conditions under which the roof and wall sections were kept (see preceding paragraph). The results of the tests conducted during the pour, at 7 and 28 days of hardening are in appendix B. This appendix also includes the various properties measured and an evaluation of the quantity of solid components in the Iso-Mix concrete.

The concrete was pumped into the pockets through a hose measuring 2 inches in diameter, a wider one would not have been suitable. During the pour, it was discovered that the pump used could not function properly with the aerated concrete. Due to the high percentage of air in this type of concrete, some problems may arise if a pump with a small diameter is used. Aerated concrete would thus not be suitable for this type of application because it cannot be pumped easily.

There were some problems getting standard concrete to flow properly along the entire length of the roof sections. The use of a vibrator on the outer wall did not aid the flow; however, when one was inserted into the pockets, the concrete flowed easily.

The Iso-Mix concrete was easy to pump and flowed easily inside the roof without the use of a vibrator.

In the case of the walls, the concrete was poured along the entire height of the extrusions in a short time span in order to check maximum deformation. Normal pour could be carried out half-way or a third of the way up the height so as to reduce deformations.

The PVC construction form did not shatter or break during the pour.

5. MEASUREMENT OF PERMANENT DEFORMATIONS ON THE PVC ELEMENTS

On February 2, 1996, three days after the pour, several measurements were taken to determine the permanent deformations caused by the weight and pressure of the concrete on the PVC elements. The concrete would have hardened sufficiently after this period and thus could no longer have deformations. The walls are made of 0.1-m wide tongues. The central lift of these tongues was measured at various positions and on both the L-shaped side and that formed by the flat elements. The results are shown in tables II to VIII. Tongue no. 1 is located on the edge of the wall and the others follow consecutively in the direction of the centre. These measurements were taken with a caliper model 500118, serial number 44.

Due to higher pressure, the lower the part of the wall from which the measurements are taken from, the higher the deformation. However, a support installed close to the bottom diminishes the deformation. The deformation on the flat elements are bigger than those on the sides formed by the Ls.

The deformations obtained do not cause any mechanical problems. Lightweight concrete such as Iso-Mix reduces the visibility of these deformations. It is also possible to pour the concrete only half- or a third of the way up the height of the walls each tirne to reduce the pressure on the PVC profiles, thus reducing deformations.

6. MEASUREIVIENTS ON THE ROOF

No measurable deformations were found between the supports, 1 m apart, for both standard and beadwall concrete. A very slight deformation was obtained at the lower free end which stretches 0.5 m beyond the last support. The values measured are indicated in table IX. In the case of the aerated and standard concrete samples, it must be pointed out that the concrete did not flow to this free end so the valued obtained could have been higher. Iso-Mix concrete flowed to the end causing only a weak deflection.

7. CUTOUT OF SAMPLES

Sections of the roof were cut out to check whether the pockets were filled with concrete. In the case of standard concrete, only the first 0.7 m were filled, the rest were empty. With Iso-Mix concrete, approximately 2.7 m of the upper part and 0.2 m of the bottom of the cavities were filled. However, for about 1.5 m close to the bottom, on!y half of the cavity was full.

This point was verified and corrected during a second pour of concrete. You will find the results in section 11.0 of this report.

8. FLAME PROPAGATION TESTS ON PVC CASING

These tests were conducted by Les Services d'Essais Inchcape NA Ltd., a laboratory certified by the Standards Council of Canada to conduct this type of testing. The results obtained are in appendix C. The flame propagation index obtained meets the flame-spread rating requirements ofthe CCMC.

9. SEEPAGE AND AIR INFILTRATION TESTS

Air-Ins Inc. conducted these tests on two walls measuring 1.3 m in width and 2.4 m in height. The wall were listed as sample nos. E005069-05 and E005069-06 and were filled with standard 30 MPa concrete and Iso-Mix concrete respectively. Air-Ins Inc. is certified by the Standards Council of Canada to perform these kinds of tests. The results obtained are detailed in Appendix D. Both samples tested meet CCMC performance requirements.

10. FREEZE/THAW BEHAVIOUR TESTS

Tests were conducted to check the behaviour of PVC and concrete samples during freeze/thaw cycles. The samples consisted of standard and Iso-Mix concrete numbered E005069-07 through E005069-15.

A Tenney model TR40, n/s 8290, conditioning chamber with an interior capacity of 1 m^3 was used. A thermocouple was installed on one of the samples to measure surface temperature . The temperature was measured with a Fluke model 52, n/s 6351132 reader.

In the beginning, we had planned to set the temperatures at -20 ° and +40 °C; however, an initial test at -20 °C showed that, even after three hours of conditioning, the surface temperature would not stabilize at the chamber's predetermined setting. The thermal inertia of concrete explains why it takes such a long time for stabilization to occur. In order to ensure that expected surface temperatures are reached, the predetermined settings in the chamber were changed to -25 ° and +45 °C. The temperature remained constant for four hours at each of these settings and moving from one extreme to the other required only about 30 minutes. Therefore, each conditioning cycle lasted nine hours. With these parameters, we were able to reach the expected values (-20 ^{0} and +40 °C) on the surface after about three hours of conditioning and -22 ° and +42 °C after four hours.

A total of 21 9-hour conditioning cycles were conducted. The chart of the temperatures reached in the chamber for one day of conditioning appears in appendix E. During the conditioning, visual checks were carried out on the samples. At low temperatures, there were no deformations or detachments between the concrete and the PVC, nor were there any detachments between the ribbed PVC surfaces and the concrete at high temperatures; however, a slight detachment, less than ½ mm, occurred between the unribbed PVC surfaces and the concrete. This deformation is negligible and will not occur in reality because the unribbed PVC surfaces are middle walls between the concrete cavities.

Once the conditioning tests were completed, a mechanical test was conducted to check the shear force between the PVC and the concrete. The ends of the sampies were cut to into flat surfaces and, in the end, the samples measured 250 mm (10 in) in length. A compressive force was applied at the four corners by pressing one end on only the concrete surface and the other solely on the PVC surface. The compressive load was gradually increased until slippage occurred making it possible to evaluate the maximum shear between the PVC and concrete surfaces. The following equipment was used for the tests:

- a vertical frame with a 10-metric-ton hydraulic actuator;
- a 661.21 A-03, n/s 3160 charge cell;
- an Instron model 8500 test set, 0.02 in/sec. movement control.

The load curves obtained for each sample will be found in appendix E and the maximum loads obtained for each sample are indicated on table X. The average value of the load obtained before slippage is 4248 N (955 Ib) for 30 MPa concrete and 3019 N (679 Ib) for Iso-Mix concrete. During sfippage, the load obtained drops to 4031 N (906 Ib) for 30 MPa concrete and to 2261 N (508 Ib) for Iso-Mix concrete.

The force obtained during slippage is lower for Iso-Mix concrete than that obtained for standard 30 MPa concrete. These differences do not influence the strength of the entire structure since only the concrete counts in the mechanical strength analyses. These differences would come into play if the composite strength of the concrete and the PVC were to be taken into consideration at a later date.

The values of the shear load indicate that a composite concrete-plastic effect was obtained. Plastic increases the safety factor obtained in the strength analyses which consider only the concrete as a structural part.

11. POUR OF CONCRETE ON ROOF SECTIONS

On October 3, 1996, concrete was poured onto four roof sections for a second time to ensure that all air pockets obtained in the first tests could be eliminated. Système Digigraph Inc. carried out this job with Iso-Mix concrete provided by the company Francon Lafarge. Mr. Claude Sauvageau of the CRIQ was present while the job was being done.

A concrete pump with a hose attached to an injector made up of a plastic tube with an inside diameter of 2 inches (50 mm) was used during the pour. The injector could be inserted approximately 6 feet deep into the roofsections.

On October 23, 1996, the hardened roof sections were cut up to check if the concrete had flowed down the entire length. All the sections, except a few small pockets along the length and in upper parts of the cavities, were filled with concrete. The largest pocket was 2.5 in. wide, 0.5 in. thick and 5 in. long. These pockets were only found on one of the four cavities in the prototype roof.

12. DISCUSSION OF THE RESULTS

The mechanical strength analyses show that standard or lightweight concrete such as Iso-Mix may be used. The thickness of the walls and roofs provides sufficient strength for conditions in Mexico and in Montreal.

There were no signs of breakage or splitting while the concrete was being put into the PVC forms. Some deformations were found in each strip of the wall. The use of lightweight concrete such as Iso-Mix would reduce the permanent deformations found in the wall. These deformations are limited when 3-mm thick extrusions are used for the walls. The deformations obtained with 2-mm thick extrusions are more serious but do not cause any mechanical problems.

They were significantly less air pockets on the roof because an injector was used to pour. Those found were small and located only on one of the four sections - they have no impact on the strength obtained. These results were obtained with Iso-Mix concrete.

Table XI features a comparison between the results of the flame behaviour, seepage and air infiltration tests and the CCMC requirements. You will notice that the requirements mentioned have been met.

13. CONCLUSION

The work conducted made it possible to verify whether the behaviour of PVC and concrete one- or two-story houses would adequately meet Canadian weather conditions and some specific requirements for Latin America. All the analyses are in appendix A and the main results in section 2. They were all conducted in accordance with the National Building Code of Canada. For Latin America, loads caused by violent winds (250 km/h) and earthquakes (0.2 W factor) were taken into consideration. The earthquake factor is equal to approximately 7 or 8 on the Richter scale.

The walls react well during pour and the roof sections fill property when an injector was used.

Depending on the type of concrete used and the installation conditions, you may need to check the roof sections periodically to see whether they are fill properly, especially in areas where the snow load is a factor. In other areas, strength requirements are lower because roof loads are lighter.

The results ofthe tests show that CCMC (Canadian Construction Materials Centre) requirements with regard to fire behaviour, seepage and air infiltration have been met

TABLE I
Description of the wall and roof sections constructed

Sample no.	Sizes	Type of concrete
E005069-01	Roof 0.4 m x 4.6 m long	Aerated
E005069-02	Roof 0.4 m x 4.6 m long	30 MPa
E005069-03	Roof 0.4 m x 4.6 m long	Iso-Mix
E005069-04	Wall 0.8 x 3.6 m high	30 MPa
E005069-05	Wall 1.3 x 2.4 m high	30 MPa
E005069-06	Wall 1.3 x 2.4 m high	Iso-Mix
E005069-07 to10	0.1 x 0.1 x 0.3 m high	30 MPa
E005069-11 to15	0.1 x 0.1 x 0.3 m high	Iso-Mix
E005069-16	Wall 0.1 m x 2.4 m high with 2 mm thick PVC tongue	30 MPa

TABLE II
Deformation ofwalls in inches - sample E005069-04
3.6 m high 30 MPa concrete watl, L-side

Height from bottom	Tongue no				Average in inches (mm)
	1	2	3	4	
150 mm	0.088	0.100	0.075	0.057	0.080 (2.0)
760 mm	0.068	0.085	0.076	0.080	0.077 (1.96)
1 780 mm	0.046	0.064	0.046	0.053	0.052 (1.3)

TABLE III
Deformation of walls in inches - sample E005069-05
2.4 m high 30 MPa concrete wall, L-side

Height from bottom	Tongue no							Average in inches (mm)
	1	2	3	4	5	6	7	
150 mm	0.019	0.028	0.068	0.073	0.065	0.057	0.050	0.051 (1.3)
610 mm	0.038	0.040	0.055	0.057	0.069	0.066	0.057	0.055 (1,4)
1 070 mm	0.032	0.030	0.057	0.056	0.062	0.060	0.049	0.049 (1.25)

TABLE IV
Deformation of walls m inches - sample E005069-06
2.4 m high lso-Mix concrete wall, L-side

Height from bottom	Tongue no							Average in inches (mm)
	1	2	3	4	5	6	7	
150 mm	0.038	0.036	0.025	0.029	0.020	0.021	0.026	0.028 (0.7)
610 mm	0.037	0.045	0.022	0.027	0.026	0.026	0..028	0.030 (0,8)
1 070 mm	0.028	0.052	0.018	0.015	0.021	0.019	0.021	0.025 (0.6)

TABLE V
Deformation of walls in inches - sample E005069-04
3.6 m high 30 MPa concrete wall, flat side

Height from bottom	Tongue no				Average in inches (mm)
	1	2	3	4	
150mm	0.116	0.126	0.149	0.132	0.131 (3.3)
760 mm	0.143	0.146	0.154	0.156	0.150 (3.8)
1 780 mm	0.108	0.128	0.103	0.112	0.113 (2.9)

TABLE VI
Deformation ofwalls in inches - sample E005069-05
2.4 m high 30 MPa concrete wall, flat side

Height from bottom	Tongue no							Average in inches (mm)
	1	2	3	4	5	6	7	
150 mm	0.025	0.066	0.067	0.089	0.085	0.094	0.095	0.074 (1.9)
610 mm	0.048	0.106	0.097	0.099	0.096	0.082	0.097	0.089 (2,3)
1 070 mm	0.033	0.044	0.080	0.065	0.074	0.073	0.075	0.063 (1.6)

TABLE VII
Deformation ofwalls in inches - sample E005069-06
2.4 m high Iso-Mix concrete wall, flat side

Height from bottom	Tongue no							Average in inches (mm)
	1	2	3	4	5	6	7	
150 mm	0.037	0.036	0.053	0.065	0.054	0.057	0.054	0.051 (1.3)
610 mm	0.071	0.071	0.070	0.074	0.076	0.082	0.079	0.075 (1.9)
1 070 mm	0.079	0.051	0.060	0.062	0.061	0.068	0.066	0.064 (1.6)

TABLE VIII
Deformation ofwalls in inches -sample E005069-16
2.4 m high 30 MPa concrete wall, 2-mm thick tongue, flat side

Height from bottom	Tongue no 1	
	Inches	mm
150 mm	0.197	5.0
610 mm	0.178	4.5
1 220 mm	0.132	3.4

TABLE IX
Deformation of roof measured in inches- free end

Sample no	Cavity no (deflection in inches)				Average in inches (mm)
	1	2	3	4	
E005069-01 Aerated concrete	0.000	0.000	0.000	0.043	0.011(0.27)
E005069-02 Standard concrete	0.000	0.021	0.024	0.064	0.027 (0.69)
E005069-03 Iso-Mix concrete	0.061	0.031	0.025	0.007	0.031 (0.79)

TABLE X
Shear between concrete and PVC

Concrete	Sample no	Max. load before slip		Min. load during slip	
		(lb)	(Newton)	(lb)	(Newton)
30MPa	E5069-07	770	3425	760	3381
	E5069-08	995	4425	940	4181
	E5069-09	1180	5249	1050	4670
	E5069-10	875	3892	875	3892
	30 MPa average	955	4248	906	4031
Iso-Mix	E5069-11	706	3140	509	2264
	E5069-12	549	2442	466	2073
	E5069-13	720	3203	514	2286
	E5069-14	756	3363	551	2451
	E5069-15	663	2949	502	2233
	Iso-Mix average	679	3019	508	2261

TABLE XI
Seepage and air infiltration and fire behaviour

Properties	Test method	Units	CCMC requirement	Results
Flame propagation	CAN/ULCS102.2	—	<150	70
Smoke emitted	CAN/ULCS102.2	——	value reported	205
Water penetration	ASTM E547-86	—	no water penetration	no water penetration
Air exfiltration	ASTM E283-84	$l/s/m^2$	<0.1	0.05 à 0.07