ROYAL BUILDING SYSTEMS™

FINISHED CONCRETE FORMS

Technical Guide

Version 4.0

Royal Building Systems™

Building Solutions for a Better World…

Welcome to the world of Royal Building Technologies (Royal), an innovative quality-driven building technologies company. Since the introduction of Royal Building Systems™ (RBS) in 1992, Royal has received global recognition for its approach in providing innovative solutions to the construction industry in residential, commercial, industrial, institutional, and agricultural sectors.

RBS is a patented polymer-based stay-in-place formwork for concrete walls. The extruded components slide and interconnect together to create a concrete formwork. The result is permanent, attractive, and pre-finished concrete walls that can be easily constructed in any climate.

RBS provides flexibility of design, whether you are building a home or a large industrial complex.

The polymer components used in Royal Building Systems™ will not decay or deteriorate over a lifespan that can be measured in decades. The RBS system also requires no painting, and resists ultraviolet radiation. Furthermore, RBS is highly durable, virtually maintenance free, impervious to weather, and extremely energy efficient.

RBS is also environmentally friendly as the polymer components are recyclable, energy efficient, and non-toxic.

Put it all together, and you can see that RBS offers complete design flexibility and an innovative building system that is easy to maintain, friendly to the environment, and built to last. Whether you are a developer, contractor, architect, engineer, or designer you can find attractive and cost effective solutions for your next project with the RBS system.

Contents

1. Introduction

This Technical Guide has been prepared by Royal Building Systems (Cdn) Limited (Royal) to assist architects, engineers, builders, and contractors in understanding and designing structures using Royal Building Systems™ (RBS). It is a part of our continuing effort to provide current and practical information to users of RBS.

The Technical Guide provides information on the following aspects of RBS:

- Material Properties
- Code Approvals
- Product Performance
- Product Specifications

In addition to the Technical Guide, the following guides are also available to assist in designing and building your projects using RBS:

- Design Guide
- Engineering Guide
- Construction Guide For Bearing Walls
- Construction Guide For Non-Bearing Walls
- Finishing, Maintenance And Repair Guide

Although every effort has been made to ensure that all the information provided in the Technical Guide is factual and that the numerical values are accurate and consistent with current engineering practice, Royal does not assume any liability for errors or oversights resulting from the use of information contained in this guide. Anyone making use of the information provided in these guides assumes all liability arising from such use.

2. Materials

RBS uses extruded rigid polymer components that serve as a stay-in-place formwork for concrete walls including load bearing walls, non-load bearing walls, shear walls, retaining walls, and foundation walls. The extruded components slide and interconnect together to create a concrete formwork that remains in place after the concrete is poured and cured.

The RBS wall components are extruded in three thicknesses (four types) as identified in Table 2.1 and Figure 2.1.

Table 2.1: RBS Wall Systems

Wall System	Wall Thickness		
	Overall	Nominal Concrete Core	Insulation(1)
RBS4	100 mm (4")	95 mm (4")	0
RBS6	150 mm (6")	145 mm (6")	0
RBS8	200 mm (8")	195 mm (8")	0
RBS8i	200 mm (8")	140 mm (6")	54 mm (2.13")

(1) The RBS8i wall system is pre-insulated with 54 mm (2.13") of polyurethane insulation. The insulation cavity is on the exterior side of the wall and is protected from the interior with the non-combustible concrete core.

2.1 Polymer Encasement

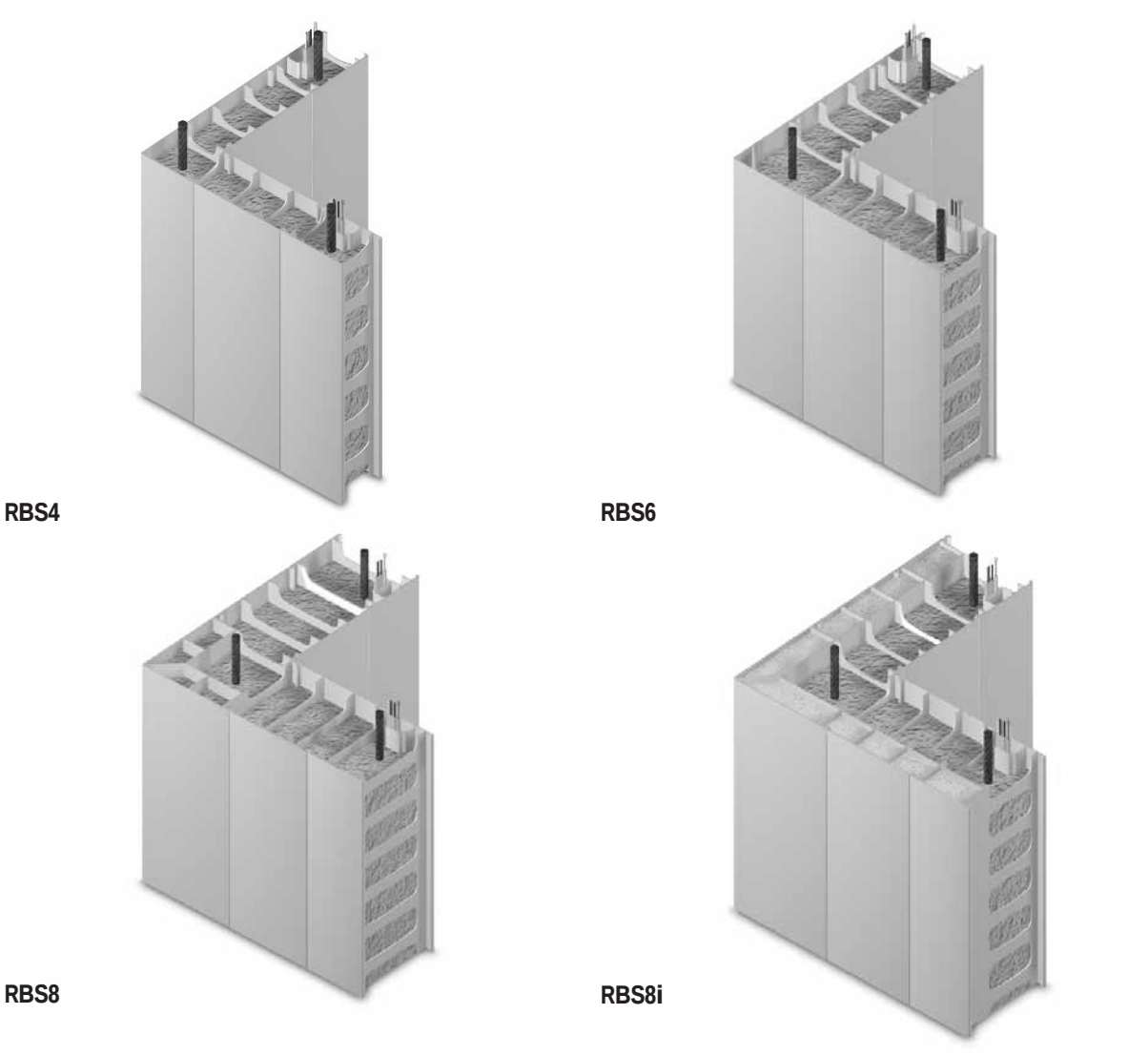
The polymer material used in RBS walls is Royalloy™ B. Royalloy™ B is a rigid polymer (polyvinyl chloride-based) composite material that has been specifically blended to produce a unique set of properties suitable for the weatherability and performance of RBS.

The physical properties of Royalloy™ B were established based on the very detailed requirements specified by the Canadian Construction Materials Centre (CCMC). To meet CCMC's requirements, a comprehensive program of tests was conducted.

Chemically, Royalloy™ B is a complex composition of polyvinyl chloride resin, acrylic modifiers, waxes, lubricants, tin stabilizer (lead stabilizers are not used), ultraviolet ray protectant, and smoke and flame suppressants. The resulting compound has a cell classification of 1 21123 32 0040, as per ASTM 4216.

Materials properties of Royalloy™ B are shown in Table 2.2.

Figure 2.1: RBS Wall Systems



RBS4

RBS6

RBS8

RBS8i

Table 2.2: Materials Properties of Royalloy™ B

Property	ASTM Test Method	Code Requirement[2]	Results[3]
Specific gravity	D792	report value	1.47
Heat deflection temperature (load 1.82 MPa) annealed at 65˚C	D648	> 70 ˚C > 158 ˚F	75 ˚C 167 ˚F
Coefficient of linear expansion	D696	$< 6 \times 10^{-5}$ cm/cm/˚C $< 3.3 \times 10^{-5}$ in/in/˚F	5.0×10^{-5} cm/cm/˚C 2.8×10^{-5} in/in/˚F
Shrinkage (1/2 hr @ 82 ˚C)	D3679	max 3	1.77
Ash content	D229	report value	28
Tensile strength	D638	> 37.7 MPa > 5468 psi	40.0 MPa 5750 psi
Tensile modulus	D638	> 2800 MPa > 406000 psi	3200 MPa 464000 psi
Elongation at yield	D638	report value	2.5 %
Elongation at break	D638	report value	127 %
Flexural strength	D790	report value	70.9 MPa 10280 psi
Flexural modulus	D790	report value	3537 MPa 513000 psi
Hardness (Rockwell)	D785	report value	102
Hardness (Shore D)	D2240	80 ± 5	77
Notched Izod impact resistance	D256	> 53.4 > 1.0	240 J/m 4.5 ft-lb/in
Drop dart impact (Procedures A & B)	D4226	> 4450 > 1.0	4982 J/m 1.1 in-lb/mil

(2) Unless otherwise noted, these are the CCMC requirements for Royal Building Systems™.
(3) Values are taken from tests reports and may not be representative of actual product.

2.2 Concrete

The second most important material used in the construction of RBS walls is concrete. Concrete comprises more than 90% (by mass and volume) of the RBS Walls. The architect or engineer shall specify the concrete mix required for each specific project. Concrete with the following minimum specifications are suggested for ease of placement:

- Minimum 28-day compressive strength
  – 20 MPa (3000 psi)
- Minimum 28-day strength with air entrainment
  – 25 MPa (3500 psi) for freeze-thaw conditions
- Maximum aggregate size
  – 10 mm (3/8")
- Minimum slump
  – 115 mm (4 1/2") at the point of discharge

2.2.1 Concrete Placement

Concrete does not segregate in the RBS Walls due to the inner webs of the Box Connectors and Panel components, which act like an elephant trunk and therefore prevent the free-fall of heavier aggregates. Honeycombing should not occur if concrete is placed correctly with a specified slump of 115 mm (4 1/2"). Concrete does not normally need to be vibrated. However, a rubber mallet may be used to tap the sides of the walls to ensure that the components are completely filled with concrete.

2.2.2 Concrete Take-off

The theoretical quantities of concrete for various RBS Walls are shown in Table 2.3 (Metric units) and Table 2.4 (Imperial units). Note that the actual quantity of concrete must be adjusted for wall openings, wastage, and specific project conditions.

Table 2.3: Concrete Take-off (Metric Units)

	RBS4	RBS6	RBS8	RBS8i
	Square Metre of Wall Area			
Per Cubic Metre of Concrete	11.1 m^2	7.2 m^2	5.4 m^2	7.5 m^2
	Cubic Metre of Concrete			
Per Square Metre of Wall Area	0.0903 m^3	0.1385 m^3	0.1867 m^3	0.1336 m^3

Table 2.4: Concrete Take-off (Imperial Units)

	RBS4	RBS6	RBS8	RBS8i
	Square Foot of Wall Area			
Per Cubic Yard of Concrete	91 ft^2	59 ft^2	44 ft^2	61 ft^2
	Cubic Yard of Concrete			
Per Square Foot of Wall Area	0.0110 yd^3	0.0169 yd^3	0.0227 yd^3	0.0164 yd^3

3. Code Approvals and Technical Publications

The following is a brief summary of the major code approvals and technical papers:

- CCMC – RBS has been evaluated by CCMC in accordance with the National Building Code of Canada (CCMC Evaluation Report 12536-R).
- OBC – Ruling of the Ontario Minister of Housing, in accordance with Ontario Building Code (Ruling No. 95-01-20-(12536-R)).
- BMEC – RBS has been authorized by the Building Materials Evaluation Commission (Ontario) to be used as non-load bearing walls in commercial and industrial applications, with unlimited building area (BMEC Authorization #A1997-21).
- ICC – RBS has been evaluated by ICC Evaluation Service, Inc. in accordance with the Uniform Building Code (ICC-ES Legacy Report ER-5174).
- BOCA – RBS has been evaluated by BOCA-ES in accordance with the BOCA National Building Code (BOCA-ES Report No. 98-40).
- ICC – RBS is presently under evaluation by ICC Evaluation Service, Inc. in accordance with the International Building Code 2003. (Report in Progress).
- 2001 – Penn State Research Report No 74, *An Innovative Building System and the Indoor Environment,* a paper presented at the International Builders Show in Atlanta
- 2000 – *Laboratory Evaluation of The Royal Building System™* for Termite Resistance, a report prepared by Dr Timothy Miles, Director of Urban Entomology Program, Faculty of Forestry, University of Toronto
- 1999 – *The Royal Building System™: Thermal Performance, Energy Consumption, and Codes*, a technical report prepared by Trow Consulting Engineers and reviewed by Dr Eric Burnett, Director, Pennsylvania Housing Research Center (Trow Report No T99-01, Revision 1, dated August 30, 1999).
- 1998 – Penn State Research Report No 51. Ranked the RBS8i Wall System as the best foundation wall system out of 8 different foundation wall systems evaluated.
- 1997 – Technical Paper presented at the Annual Conference of American Society of Civil Engineers in Minneapolis.
- 1996 – Technical Paper presented at the Annual Conference of American Society of Civil Engineers in Washington DC.

4. Product Performance

4.1 Weatherability of Royalloy™ B

Royalloy™ B has been specifically designed to resist fading and discoloration due to weathering.

Accelerated weathering tests (Table 4.1), as well as outdoor weathering tests (Tables 4.2-4.4) have been conducted.

Table 4.1: Weathering Properties of Royalloy™ B – Accelerated[3]

Property	Units	ASTM Test Method	Results
Yellowness Index	ΔYI	D1925	+ 2.15
	ΔYI	E313	+ 1.87
Color Retention (Hunter Units)	ΔE	D2244	+ 0.98
	ΔL	D2244	- 0.34
	Δa	D2244	+ 0.01
	Δb	D2244	+ 0.92
Drop Dart Impact	% Retention	D4226	97

Table 4.2: Weathering Properties of Royalloy™ B – Outdoor[4] (Arizona)

Property	Units	ASTM Test Method	Results	
			6 months	1 year
Yellowness Index	ΔYI	D1925	1.16	0.09
	ΔYI	E313	0.98	0.19
Color Retention (Hunter Units)	ΔE	D2244	0.54	0.48
	ΔL	D2244	-0.19	0.12
	Δa	D2244	- 0.05	- 0.15
	Δb	D2244	0.50	0.12
Drop Dart Impact	% Retention	D4226	88.1	81.3

Table 4.3: Weathering Properties of Royalloy™ B – Outdoor[4] (Chicago)

Property	Units	ASTM Test Method	Results	
			6 months	1 year
Yellowness Index	ΔYI	D1925	- 0.35	- 0.18
	ΔYI	E313	- 0.26	- 0.16
Color Retention (Hunter Units)	ΔE	D2244	0.18	0.93
	ΔL	D2244	- 0.08	- 0.89
	Δa	D2244	- 0.04	- 0.01
	Δb	D2244	- 0.15	- 0.02
Drop Dart Impact	% Retention	D4226	100.0	100.0

Table 4.4: Weathering Properties of Royalloy™ B – Outdoor[4] (Florida)

Property	Units	ASTM Test Method	Results	
			6 months	1 year
Yellowness Index	ΔYI	D1925	- 0.16	- 0.49
	ΔYI	E313	- 0.13	- 0.39
Color Retention (Hunter Units)	ΔE	D2244	0.64	0.49
	ΔL	D2244	- 0.60	- 0.26
	Δa	D2244	- 0.01	- 0.03
	Δb	D2244	- 0.16	- 0.25
Drop Dart Impact	% Retention	D4226	92.7	96.0

Notes:
ASTM D1925 discontinued in 1995
Color changes are in Hunter units
∅YI – change in yellowness index
∅E – total color change
∅L – change in lightness/ darkness direction
∅a – change in red/ green direction
∅b – change in yellow/ blue direction

(3) 2000-Hour accelerated weathering tests conducted in accordance with ASTM G53.
(4) Outdoor weathering conducted in accordance with ASTM D1435.

4.2 Fire Performance of Royalloy™ B

The fire performance of Royalloy™ B is shown in Table 4.5.

Table 4.5: Fire Performance of Royalloy™ B

Fire Performance	Test Method	Code Requirement[5]	RBS Results
Self-ignition temperature	ASTM D1929	min 343 ˚C 650 ˚F	480 ˚C 896 ˚F
Flash-ignition temperature	ASTM D1929	none none	460 ˚C 860 ˚F
Rate of burn	ASTM D635	10 mm/sec 0.394 in/sec	0 0
Maximum extent of burning	ASTM D635	max 25.4 mm 1.0 in	12.4 mm 0.49 in
Flame spread[6]	ASTM E84 ULC S102.2	max 25 < 150	≤ 25 ≤ 25
Smoke Development[6]	ASTM E84 ULC S102.2	max 450 report value	≤ 450 ≤ 350
Flash Fire Propensity (time to flash fire in seconds)	Footnote 6	None	None

4.3 Fire Performance of Concrete-Filled RBS Walls

RBS walls have a structural base of noncombustible concrete. In accordance with the definition provided in Section 703.4.2 of the International Building Code (IBC 2003), RBS walls are considered noncombustible. Thus, the fire resistance rating of RBS walls is similar to that of a concrete wall. Nonetheless, to confirm that the polymer webs do not impact the fire resistance performance, concrete-filled RBS walls have been tested and evaluated for fire resistance. Additionally, RBS walls have also been exposed to various fire tests for evaluation of performance of the exterior face of the walls. Following is a summary of the full-scale fire tests conducted:

- CAN/ULC S101, *Standard Methods of Fire Endurance Tests of Building Construction and Material* (Equivalent to ASTM E119). Based on this test the fire resistance rating of RBS has been confirmed. The ratings are shown in Table 4.6.

(5) Most stringent of CCMC requirements for Royal Building Systems™, or U.S. building code requirements.

(6) FLAME SPREAD AND SMOKE DEVELOPMENT RATINGS
The numerical flame spread and smoke development ratings set out herein are not intended to reflect hazards presented by any Royal Building Technologies products, including the Royal Building Systems concrete forming system, or any other material under actual fire conditions. These ratings are determined by small-scale tests conducted by independent testing facilities using the ASTM E-84 (American Society for Testing and Material) test standard. ROYAL BUILDING TECHNOLOGIES PROVIDES THESE RATINGS FOR PRODUCT COMPARISON PURPOSES ONLY. Like other many building materials (e.g. wood), panels made of polyvinyl chloride (PVC) will burn. When ignited, PVC may produce dense smoke which may be toxic. Proper fire safety considerations require proper design of a facility and the fire suppressions systems used, as well as necessary precautions during construction and occupancy. Local codes, insurance requirements, and any special needs of the product user will determine the correct fire rated interior finish and fire suppressions system necessary for a specific installation.

- CAN/ULC S101, 15-minute remain-in-place test. This test allows the RBS walls with external insulation and stucco finish on the exterior face to be used as exterior walls in noncombustible construction.
- CAN/ULC S134, *Standard Method of Fire Test of Exterior Wall Assemblies*. This test method provides an assessment of fire spread, vertically and horizontally, on the exterior face of non-load bearing exterior wall assemblies. This method evaluates the performance of the cladding of a wall from fire exposure resulting from a post-flashover fire in a compartment venting through an opening in the wall.

Table 4.6: Fire Resistance of RBS Walls

Wall System	Overall Thickness	Nominal Concrete Core Thickness	Minimum Fire Resistance
RBS4	100 mm (4")	95 mm (4")	45 minutes[6]
RBS6	150 mm (6")	145 mm (6")	2 hours[7]
RBS8	200 mm (8")	195 mm (8")	2 hours[6]
RBS8i	200 mm (8")	140 mm (6")	2 hours[6]

4.4 Acoustic Performance of Concrete-Filled RBS Walls

Almost all building codes require that walls separating dwelling units from each other or from public or service areas have a Sound Transmission Class (STC) of not less than 50 (or 45 if field tested). STC is established in accordance with ASTM E90, *Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements.* Whereas field testing is conducted in accordance with ASTM E336, *Standard Test Method for Measurement of Airborne Sound Insulation in Buildings.*

The acoustic testing of the RBS Walls was conducted in accordance with ASTM E336. Based on this testing, the sound transmission of concrete-filled RBS walls is summarized in Table 4.7. A FSTC rating of 45 is considered equivalent to a STC rating of 50.

Table 4.7: Sound Transmission Rating of RBS Walls

Wall System	Overall Thickness	FSTC Rating	STC Rating
RBS4	100 mm (4")	48	52
RBS6	150 mm (6")	47	52
RBS8[8]	200 mm (8")	50	55
RBS8i	200 mm (8")	53	58

4.5 Energy Performance

Three major factors affecting the thermal performance of a wall system are **thermal bridging, air tightness** of the enclosure, and **thermal mass**. The combined effect of these factors is generally not considered when comparing the thermal performance of a building system. Normally, a simple R-value is quoted. Studies have shown that the simple comparison of quoted R-values is not an appropriate method of comparing the thermal performance of different building systems.

Thermal bridging is caused by wood or steel members, especially in light-frame construction. These members can act as a thermal bridge causing heat flow to short-circuit. Unlike RBS, framed systems can suffer from severe thermal bridge heat loss, especially at corners, windows and partitions (see Figure 4.1). For instance, a 2" x 6" wood framed wall with a drywall interior finish and vinyl siding can be shown

(6) Based on Engineering study and the fire test described in footnote 7.
(7) Based on the fire testing conducted on a vertically reinforced (10M bars at 333 mm o/c) and horizontally reinforced (10M bars at 333 mm o/c) RBS6 wall assembly; the test was conducted at ULC (Underwriters Laboratory of Canada) in accordance with the Canadian Standard CAN/ULC-S101-M89 (equivalent to ASTM E119).
(8) Based on the thickness of concrete, it is estimated that RBS8 wall will have a minimum of STC rating of 55.

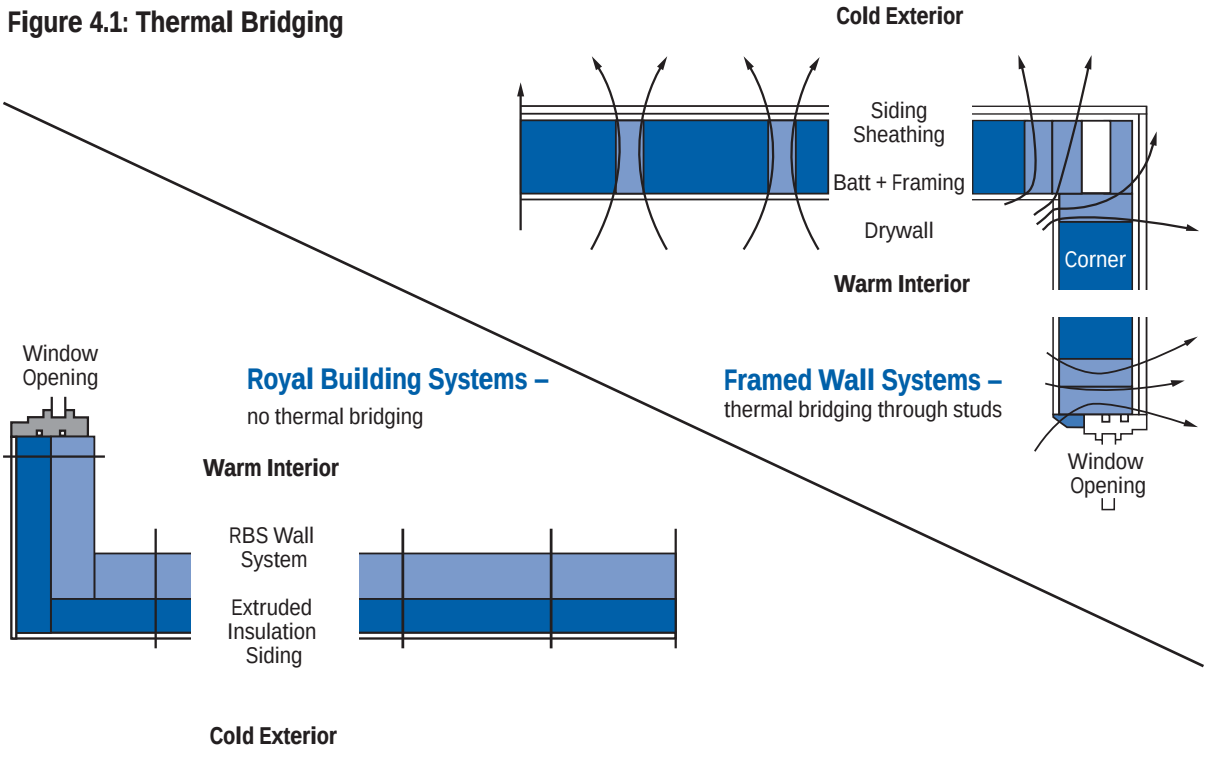
to have a nominal R-value of 21.5 (RSI 3.79), using R19 batt. When the extra thermal bridging inherent in framing around doors and windows is accounted for, ASHRAE[9] considers such a wall to have an R-value of 13.7 (RSI 2.41). Therefore, a 2" x 6" wall system would not meet the requirements of the ASHRAE standard for residential buildings in colder regions such as Michigan, or North Dakota.

Air leakage through the building enclosure can be a major source of energy loss, approximately 30% to 50%. Airtight buildings use far less energy through the building envelope. The RBS walls provide a tighter building envelope compared to many conventional building systems, without the use of an additional air barrier. For instance, RBS4 wall system (4" concrete-filled wall) has an air leakage rate of 0.020 L/(s • m^2) (0.0039 ft^3/(min • ft^2)) at a pressure differential of 75 Pa (1.57 psf). This is the same level of airtightness required from a 6-mil thick sheet of polyethylene when used as air barrier. However, this is much better than the tightest air barrier system with an air leakage rate of 0.05 L/(s • m^2) (0.01 ft3/(min • ft^2)) required by the National Building Code of Canada.

Thermal mass effect in RBS walls is provided by the thermally insulated concrete. This thermal mass effect provides for significantly lower space-conditioning energy consumption when compared to lightweight wall systems with the same nominal R-value. In some climates, the effective R-value of an RBS wall will be twice that of framed wall insulated to the same nominal level.

This was further confirmed by a study conducted by Trow Consulting Engineers Ltd. The results of this study are summarized in Table 4.8. For further details, please refer to Trow Report No T99-01, Rev 1, dated August 30, 1999.

Figure 4.1: Thermal Bridging



(9) The American Society of Heating, Refrigerating and Air-Conditioning Engineers, is an international organization of 50,000 persons with chapters throughout the world. The Society is organized for the sole purpose of advancing the arts and sciences of heating, ventilation, air conditioning and refrigeration for the public's benefit through research, standards writing, continuing education and publications. ASHRAE writes standards that set uniform methods of testing and rating equipment and establish accepted practices for the HVAC&R industry worldwide, such as the design of energy efficient buildings.

Table 4.8: Mass Benefits of RBS Walls in Various Climates[10]

City	ORNL Estimated Equivalent R-Value for:			
	R11.9 Walls[1] (RSI 2.10 or U = 0.477)	**R14.3 Walls[2] (RSI 2.52 or U = 0.397)**	**R16.9 Walls[3] (RSI 2.98 or U = 0.336)**	**R19.4 Walls[4] (RSI 3.42 or U = 0.293)**
	RBS4, RBS6, or RBS8 + 2" EXP	**RBS4, RBS6, or RBS8 + 2 1/2" EXP or RBS8i**	**RBS4, RBS6, or RBS8 + 3" EXP**	**RBS4, RBS6 or RBS8 + 3 1/2" EXP**
Atlanta	R25.1 (RSI 4.42 or U=0.226)	R30.2 (RSI 5.32 or U=0.188)	R36.3 (RSI 6.39 or U=0.156)	R41.7 (RSI 7.34 or U=0.136)
Denver	R22.4 (RSI 3.94 or U=0.253)	R26.9 (RSI 4.74 or U=0.211)	31.3 (RSI 5.51 or U=0.181)	R35.9 (RSI 6.32 or U=0.158)
Miami	R26.2 (RSI 4.61 or U=0.217)	R31.5 (RSI 5.55 or U=0.180)	R41.2 (RSI 7.25 or U=0.138)	R47.3 (RSI 8.33 or U=0.120)
Minneapolis (similar to Toronto)	R17.7 (RSI 3.11 or U=0.321)	R21.3 (RSI 3.75 or U=0.267)	R24.8 (RSI 4.37 or U=0.229)	R28.5 (RSI 5.01 or U=0.199)
Phoenix	R30.6 (RSI 5.39 or U=0.186)	R36.8 (RSI 6.48 or U=0.154)	R41.6 (RSI 7.33 or U=0.136)	R47.7 (RSI 8.40 or U=0.119)
Washington (similar to Vancouver)	R21.4 (RSI 3.77 or U=0.265)	R25.7 (RSI 4.53 or U=0.221)	R30.9 (RSI 5.44 or U=0.184)	R35.5 (RSI 6.25 or U=0.160)

R = thermal resistance [$ft^2 \cdot hr \cdot {}^\circ F$/Btu]
RSI = thermal resistance [$m^2 \cdot k$/W]
U = thermal conductance [W/($m^2 \cdot K$)]

1. The ORNL values are based on a wall with 1/2" drywall, 4" of solid concrete, and R12 exterior insulation (total R-value of 13.0). The RBS4, RBS6, and RBS8 walls with 2" (steady-state R11.9) of extruded polystyrene sheathing having slightly less exterior insulation.
2. These values have been interpolated from the ORNL values of R13 and R17.2 walls. The RBS4, RBS6, and RBS8 wall with 2 1/2" (steady-state R14.3) of extruded polystyrene sheathing or RBS8i walls with 2 1/8" of integrated polyurethane insulation have slightly more or less exterior insulation and interior thermal mass.
3. The ORNL values are based on a wall with 1/2" drywall, 6" of solid concrete, and R16 exterior insulation. The RBS4, RBS6, and RBS8 walls with 3" of extruded polystyrene sheathing (R16.9) have slightly more exterior insulation and the same or slightly less interior thermal mass.
4. These values have been interpolated from the ORNL values of R13 and R17.2 walls. The RBS4, RBS6, and RBS8 wall with 3 1/2" (steady-state R19.4) of extruded polystyrene sheathing having slightly more exterior insulation.

(10) Based on research by Oak Ridge National Laboratory (ORNL). Researchers at ORNL investigated the effect of thermal mass on annual energy consumption in a range of US climates. Employing the same representative, one-story ranch-type house, the ORNL researchers modeled the space-conditioning energy consumption over a typical year for houses with both lightweight and massive walls. The base house in all cases had a lightweight roof assembly insulated to R30. The contribution of air leakage was assumed to be the same for all homes.

4.6 Vapor and Air Barriers

The two layers of 0.100" thick polymer encasement of RBS walls act as the vapor barrier. In conventional construction, typically, a 0.006" thick sheet of polyethylene is used. As stated earlier, when RBS walls are filled with concrete, they act as an air barrier. For instance, RBS4 wall system (4" concrete-filled wall) has an air leakage rate of 0.020 L/(s • m^2) (0.0039 ft^3/(min • ft^2)) at a pressure differential of 75 Pa[11] (1.57 psf). Therefore, additional air and vapor barriers are not required when using RBS walls.

4.7 Water Penetration

Tests have been conducted to determine the water resistance RBS walls.

For above-grade use, water penetration testing was conducted in accordance with ASTM E547[12]. The testing was conducted up to a pressure differential of 700 Pa (14.6 psf) across the wall. It was established that RBS walls are watertight without the use of additional cladding.

Also for below-grade or basement use, the RBS8i wall was tested under a 5-foot column of water. During the 24-hour test period no water infiltrated the interior face of the wall. For complete test results, please refer to Trow report dated August 26, 1997. The testing established that the RBS8i wall did not require additional dampproofing or drainage layer on the outside when used below-grade, if build in accordance with the installation instructions provided by Royal.

4.8 Indoor Air Quality (IAQ)

In recent years, Indoor Air Quality (IAQ) has become a serious concern, especially due to "off-gassing" and mold growth in houses and schools. The resulting poor IAQ has serious health implications. Epidemiological studies from the U.K., the Netherlands, Sweden, and Canada have consistently shown negative health effects associated with dampness and mold. In children, symptoms most commonly associated with mold include respiratory problems, aches and pains, diarrhea, and headaches. In adults, the symptoms can include aching joints, nausea and vomiting, backache, blocked nose, and breathlessness.

As discussed in the following subsections, RBS does not contribute to poor IAQ, but further enhances the IAQ by providing a building system that does not off-gas and that is mold and mildew resistant.

4.8.1 "Off-Gassing"

Testing and chamber studies[13] have been conducted to assess the Indoor Air Quality of The Royal Building System™ homes[14]. The objective was to assess the contribution of volatile organic compounds (VOC), or "off-gassing", associated with the extruded PVC building components to the concentration of the total VOC (TVOC) found in the indoor air.

Based on the testing and analysis, the following was concluded:

- The average TVOC concentration found in three model homes tested for IAQ was less than 0.3 mg/m^3. This is significantly less than 1.0 – 2.0 mg/m^3 typically found in occupied houses and offices.
- Chamber studies indicated that in the worst-case scenario (a house built using the RBS system and occupied only one month after the building components were extruded – representing the maximum amount of off-gassing from the new material), the concentration of 0.04 mg/L (mg/m^3) would contribute less than 15% to the TVOC found in the model homes. Note that the concentration of 0.04 mg/m^3 is reaching the limit of analytical detection.
- The "off-gassing" from the extruded RBS components is significantly less than the off-gassing associated with conventional building products such as: natural wood, laminated wood, particle board, various walls covering, etc.

(11) See Trow Report No T93-24, dated October 29, 1993.
(12) See Trow Report No T93-25, dated November 12, 1993.
(13) Chamber testing of the extruded RBS building components was conducted in June 1997. For a complete report, please refer to Alara Report #9736, dated August 18, 1997
(14) Indoor air-quality tests were conducted in January, 1997. For more details, please refer to Alara Report #9701, dated February 11, 1997.

No health hazards or discomfort has been associated with the TVOC levels found in the three model homes tested for IAQ.

4.8.2 Mold and Mildew

The growth of biological pests is assisted and promoted by wet building materials such as gypsum wallboard and wood. These conventional building materials get wet through absorption of water from high indoor humidity (condensation caused by thermal bridging), through moist air leaking through the building envelope and depositing its moisture before exiting the envelope, or simply by rain/ground water penetrating the interior of the building.

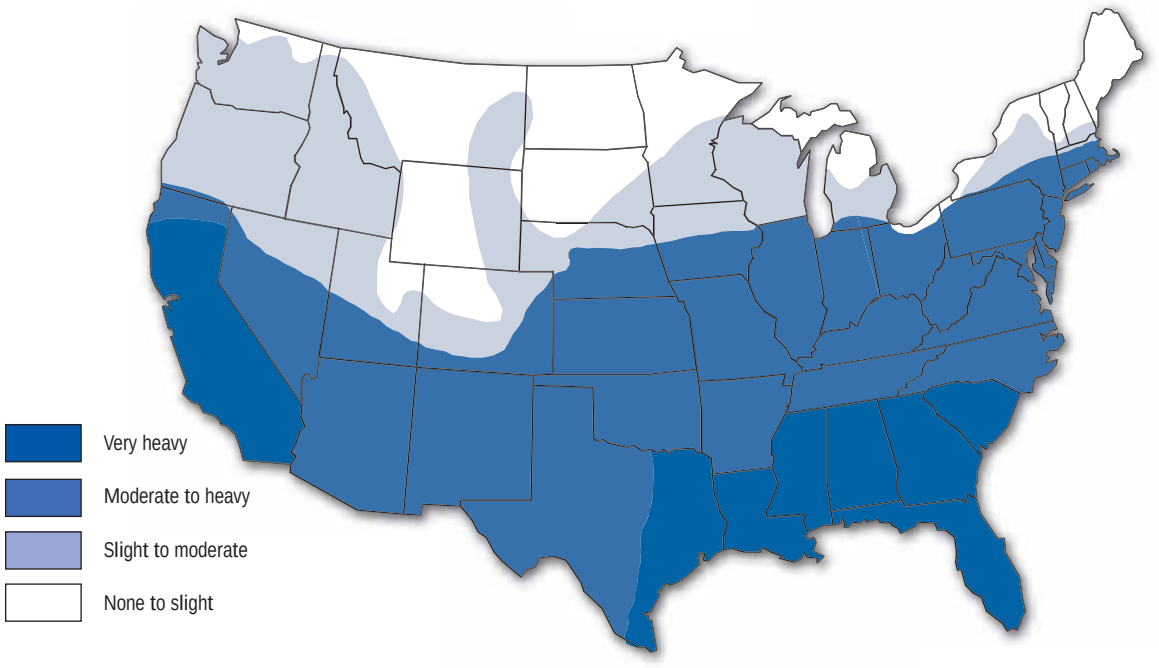
RBS does not promote or allow the growth of mold and mildew as moisture does not penetrate the interior, and because the polymer surface does not absorb and store moisture. Even high indoor humidity levels do not damage the interior of the building, as the polymer surface of the wall is moisture resistant and vapor impervious.

4.9 Termites

Termites are wood eating insects that live in organized communities. There are two basic types of termites, those that live entirely in wood, and those that can tunnel into the ground, also known as subterranean termites. The latter is the most destructive insect to the structure of a building. Each year in North America, termites cause billions of dollars of damage to buildings. According to University of California Pest Management Guidelines, termites are the most destructive wood-destroying insects in the USA. At least 1% of the housing units in the USA require treatment each year for the control of termites. As shown in Figure 4.2, more than half of the USA is infested with termites. Termites are beginning to appear in the colder climates of the Northern USA and Southern Canada. Recognizing this problem, building codes are requiring protection against termites to be considered in the design of foundation walls.

Figure 4.2: Termite Infestation Probability Map

NOTE: Lines defining areas are approximate only. Consult local conditions.



Prevention is one of the three major ways of protecting against termites. The other two being remediation (treating soil with termiticide, a chemical control) and suppression (this method aims at killing some or all of the members of a colony).

Prevention can be achieved by proper design and the selection of a termite resistant material that is not prone to cracking and that does not contain concealed entry points for termites to enter the building. Conventional materials and construction methods, specifically wood framing, have not been able to achieve effective prevention. Similarly, cracking of concrete foundations (concrete block and cast-in-place concrete) provides concealed entry points for termites.

All of these problems, which lead to termite vulnerability, are effectively eliminated by RBS. Furthermore, the System remains impregnable over time. Even if settlement or seismic activity causes cracking of the concrete, the cracks are never accessible to termites as all of the concrete is uniformly encased in the durable polymer shell.

To further confirm this, a detailed laboratory evaluation was conducted by Dr. Timothy G. Myles, Director of the Urban Entomology Program, Faculty of Forestry, University of Toronto. The study[15] concluded:

"In conclusion, the component materials of The Royal Building System, the Royalloy B and the polyurethane insulation, are termite resistant. The building system itself, is also resistant to termite surface foraging because of the smoothness which prevents termites from successfully climbing or building shelter tubes over the surface. Furthermore, the tight fit of the interlocking elements results in few surface features that would attract termites and even the groves between the elements do not elicit shelter tubing. In addition, the monolithic construction of each element leaves no opening for termites to enter. All of these features combine to create a building system which is invulnerable to the destructive power of termites."

4.10 Structural Performance

Royal Building Systems™ is a result of many years of research and development. Considerable structural testing has been conducted both "in-house" and through third parties. Royal has retained the services of several independent accredited testing laboratories, technical experts, and product evaluation agencies, to conduct numerous testing programs on various aspects of RBS and to prepare engineering and evaluation reports.

RBS walls are composed of cored box connector and panel components that are filled with concrete. The polymer components provide a stay-in-place formwork and permanent wall finish. The polymer components are cored and are filled with concrete to provide a monolithic concrete wall. Since the polymer components completely encase the concrete within the walls, the polymer and concrete create a composite member reinforced by the polymer. The wall can be reinforced with steel reinforcing bars that are added to the wall, as required, prior to placing the concrete.

RBS may be designed using two different design methods:

1. Plain Concrete Design
2. Steel Reinforced Concrete Design

The first method is used when plain concrete provide adequate strength and no additional reinforcement is required. For example foundation walls may be designed using this method.

(15) Laboratory Evaluation of Royal Building Systems™ for Termite Resistance, dated June 2000, a report prepared by Dr Timothy Miles, Director of Urban Entomology Program, Faculty of Forestry, University of Toronto

The second design method is used when fire-rated construction is required or axial loads are large.

The design methods are governed by existing codes and standards for the design of the walls. The applicable design standard in Canada is CSA Standard A23.3, Design of Concrete Structures. In the USA, ACI 318, Building Code Requirements for Structural Concrete, is used.

The design approach along with detailed design tables showing the physical properties and flexural resistance, have been developed and are contained in the Engineering Guide.

Testing on RBS has been conducted in many countries around the world, including the USA, Canada, Argentina, Japan, and China, for local approvals and performance evaluation of the System. Following is a brief list of some of the structural tests conducted:

- Gravity load testing (simulating superimposed dead, live, and snow loads)
- Pressurization testing (simulating high wind loads)
- Lateral load testing (simulating seismic loading)

Based on the above testing, Royal has demonstrated compliance of RBS with the applicable building requirements. These tests demonstrated that RBS performs extremely well in high winds and has excellent seismic response, with little or no debris. The concrete is encased by the polymer shell, which provides confinement for the concrete during extreme seismic activity.

5. Product Specifications

The following specifications are general in nature. Application-specific RBS specifications are also available in CSI format.

Section 03140 – Polymer-Encased Concrete Walls

Part 1– General

1.1 Description

1. Comply with the General Conditions, Supplementary Conditions and the requirements of Division 01.

1.2 Work Included

1. Design, supply, delivery and installation of Royal Building Systems™, polymer-encased concrete walls.
2. Supply and installation of all reinforcing steel within RBS walls.
3. Supply and placement of concrete into RBS walls.
4. Supply and installation of all formwork and bracing for the RBS walls.
5. Supply and installation of caulking for all joints.

1.3 Material Installed but not Specified or Supplied Under This Section

1. Sleeves required by other divisions.
2. Inserts required by other divisions
3. Anchors required by other divisions

1.4 Work By Others

1. Supply and installation of reinforcing steel dowels in the foundations.
2. Supply and installation of permanent steel framing, as required.
3. Supply and installation of doors and windows
4. Supply and installation of roof deck and roofing.
5. Supply and installation of wall cap and flashings.

1.5 Related Work Under Other Sections

1. Section 03200 – Concrete Reinforcement
2. Section 03300 – Cast-In-Place Concrete
3. Section 05100 – Structural Steel
4. Section 05300 – Steel Decking
5. Division 07000 – Roofing
6. Division 08000 – Doors & Windows
7. Division 10000 – Sealants and Flashings

1.6 Reference Standards

1. All codes, standard specifications, and by-laws referred to in this section shall be current editions including all latest revisions, addenda and supplements.
2. ASTM 4216-92, Standard specification for Rigid Poly (Vinyl Chloride) (PVC) and related plastic building products compounds
3. CAN/ULC S102.2-M88, Standard Method of Test for Surface Burning Characteristics of Flooring, Floor Covering and Miscellaneous Materials
4. ASTM E84, Surface Burning Characteristics of Building Materials
5. CSA Standard A23.3, Design of Concrete Structures
6. ACI 318, Building Code Requirements for Structural Concrete.
7. CAN/ULC S101-M89, Standard Methods for Fire Testing of Building Construction and Materials
8. CAN/ULC S134-92 Standard Method for Fire Testing Exterior Wall Assemblies

1.7 Design

1. Design and fabricate the RBS walls and anchors so that they will adequately sustain themselves and superimposed wind, seismic, and snow loads.
2. The design loads shall be in accordance with local building codes and standards.
3. Assume full responsibility for the design, for the adequacy, and for the safety of all formwork and falsework for the RBS walls.

1.8 Submittals

1. Submit copy of Manufacturer's Installation Manual.
2. Prepare and submit copies of erection shop drawings in accordance with Division 01 – General Conditions.
3. Shop drawings shall indicate:
    1. Dimensions related to work by others,
    2. Component types and lengths,
    3. Reinforcing steel sizes, lengths, and locations,
    4. The locations of control joints and expansion joints,
    5. Connection details,
    6. Openings, sleeves, inserts, and anchors as required by other divisions.
4. Conform to the requirements of Building Authorities and Regulatory Agencies including submission of required shop drawings.
5. Shop drawings and/or calculations shall bear the stamp and signature of the registered Professional Engineer responsible for the design. The Professional Engineer shall be familiar with the design and construction of RBS walls
6. Submit certified copies of mill test reports of the reinforcing steel supplied, if requested.

1.9 Quality Assurance

1. Contractor shall engage an installation contractor, (Installer), who has been qualified by Royal Building Systems (Cdn) Limited for the installation of Royal Building Systems™. Alternatively, contractor shall engage a technical representative, (Technical Advisor), usually a staff member of Royal Building Systems (Cdn) Limited who is qualified to instruct and supervise the installation crew on site for the duration of the work under this Section.
2. Installer or Technical Advisor shall furnish proof of qualifications to Contractor prior to commencement of work under this Section.
3. Installer or Technical Advisor shall meet with the Contractor prior to material delivery on site to co-ordinate provisions for access, storage area, and protection of RBS product in accordance with the Manufacturer's Construction Guide.
4. Cost of any independent inspection required by the owner to verify compliance with the section is to be paid by the owner.

1.10 Samples

1. If requested, submit up to 4 samples, 300 mm (12") long, of a box connector, panel and one other component, for each color and wall each wall type, as directed by the Architect.
2. Site Mock-up: If required, construct a sample 1200 mm x 1200 mm (4' x 4') wall mock-up to include full wall system and details, as directed by Architect. Sample wall mock-up may form part of finished work if approved by Architect.

1.11 Delivery, Storage & Handling

1. Deliver products in good condition, bearing identification of the product and erection label.
2. Handle and store products in location to prevent damaging and soiling.

1.12 Warranty

1. Provide a standard written warranty with duration of one (1) year in accordance with Division 01 - General Conditions.
2. Owner shall contact the Manufacturer for a written copy of specific warranties for the RBS material.

1.13 Safety Requirements

1. Provide safety cables, harnesses, railings, barricades and other safety equipment and protection where work under this section is in progress and as required by Regulatory Safety Agencies.

Part 2 – Products

2.1 RBS Materials

1. The components of Royal Building Systems™ walls shall be manufactured by:

   Royal Building Technologies
   A division of Royal Group Technologies Inc.
   1 Royal Gate Blvd.,
   Woodbridge, Ontario, Canada L4L 8Z7
   Phone: (905) 652-0001 or
   Toll-free 1 (877) 747-WALL (9255)
   Fax: (905) 652-0002
   E-mail: info@rbsdirect.com
   Web Page: www.rbsdirect.com

2. Substitutes and alternates will not be accepted.
3. Provide Royal Building Systems components as listed below or as may be required, for proper execution of the work.
   1. Box connectors – straight, corner, end, 3-way, 4-way, 45° corner (inside or outside)
   2. Panels – 232, 182, 132 and 93
   3. Spacers – 68, 49
   4. Box Joiners
   5. Starters
   6. Multi-story band, cap and cover
4. Provide new material equal in all respects to those specified.

2.2 Concrete

1. Concrete supplied and placed, under this section, shall be pre-mixed as specified under Section 03300 and as herein specified.
2. The concrete shall have a minimum 28-day compressive strength of 20 MPa (3000 psi) or as specified by the design engineer.
3. The Portland cement shall be Type 10.
4. The nominal size of the coarse aggregate shall not exceed 10 mm ($^3/_8$").
5. The concrete shall have a maximum water/cement ratio of 0.55 by mass. Provide a water-reducing admixture in all concrete.
6. The concrete slump shall be 100 mm (4") to 125 mm (5") at the point of discharge. Addition of water at the job site is not permitted.
7. Calcium chloride admixtures or chloride-based admixtures shall not be used.
8. Salt or other chemicals shall not be added to reduce the freezing point of any concrete.
9. Fly Ash will not be accepted in any concrete.
10. Cementitious hydraulic slag shall not incorporate into any concrete, without prior written permission from the Installer or the Technical Advisor. Approval is dependent on proven performance and prevalent weather conditions.

2.3 Reinforcing Steel

1. Reinforcing steel supplied and placed, under this section, shall be as specified in Section 3200 and as herein specified.
2. Reinforcing bars shall be new deformed "Hi-bond" bars conforming to ASTM A615 with a minimum yield stress of 400 MPa (60 ksi) or CSA Standard G30.18 with f_y =400 MPa (Grade 400). All bars shall have typical identification patterns.
3. Wire O-Rings shall be tack welded to the vertical bars, at 3000 mm (10') maximum, (two minimum per bar), to correctly locate the bars within the cells of the wall components.

Part 3 - Execution

3.1 Examination

1. Verify that the site conditions, as required by this Section, are as set out in Division 01 – General Conditions, and in accordance with the Manufacturer's Construction Guide.

2. Examine to determine that foundations installed under Division 03000 are within acceptable tolerances of level, dimensions and locations. Refer to clause 3.9 on tolerances.
3. Examine to determine that structural steel installed under Division 05000 is as specified and within acceptable tolerances of specified locations. Refer to clause 3.9 on tolerances.
4. Examine to determine that reinforcing steel dowels are at specified locations and spacings and within acceptable tolerances. Refer to clause 3.5
5. Report any discrepancies which affect the work of this Section.

3.2 Preparations

1. Clean all dirt and debris from top of footings prior to commencing work.
2. Remove all snow and ice from the top of foundations, prior to placing the RBS walls.
3. Before concrete is placed, all anchors, reinforcing steel, formwork and bracing must be in place and reviewed.

3.4 Installation

1. Installation of RBS walls shall be performed by an Installer or supervised by a Technical Advisor as required by this Section.
2. Installation shall be in accordance with Manufacturer's Installation Manual as supplied under this Section.
3. The Installing Contractor shall ensure Manufacturer's Procedures for the following work are employed on site:
    1. Project Organization
    2. Materials
    3. Equipment
    4. Site Preparations
    5. Building Preparations
    6. Safety
    7. Wall Erection
    8. Concrete Work
    9. Clean-Up
    10. Finishing

3.5 Reinforcing Steel Placement

1. Vertical reinforcing steel shall be installed in the cells of the box connectors or panels, as specified, and held in place by wire hoops tack welded to the bars and placed diagonally across the cells.
2. Horizontal bars shall be placed, as required, continuously over openings and extend 610 mm (2') minimum each side of the openings.
3. Place reinforcing steel within the following tolerances:
    1. Cover protection of reinforcement ± 8 mm (± $^{5}/_{16}$")
    2. Lateral and vertical spacing 25 mm (1")
4. All reinforcing steel shall be clean and free of deleterious materials.

3.6 Service Penetrations

1. Assist and co-ordinate with all trades in the preparation of a drawing showing the type, extent and location of items to be cast in and openings to be formed in the walls. This drawing must be submitted for review and approval prior to factory penalization of walls.
2. Openings shall be cut and sleeves or form-outs provided for service penetrations (e.g. conduits, piping, ductwork etc.) at the required locations as indicated by the shop drawings by the appropriate trades.
3. All openings required by other trades that are not indicated on the shop drawings and that have to be site cut before or after the concrete is poured, shall be done by this section and all costs shall be the responsibility of the appropriate trade.
4. Prior to concrete placement, cut openings and install PVC pipe sleeves or wood formwork, provided by others up to 225 mm square (9" square) at service penetrations to create voids where services can be passed through the wall at a later date
5. Service penetrations exceeding 225 mm (9") in width or spaced closer than 3 times the diameters on center shall be reinforced as required.

3.7 Concrete Placement

1. Concrete placement shall conform to Section 03300 and as herein specified.
2. Notify the Architect, at least 24 hours before any concrete placing is to proceed, for a review of the preparations.
3. Co-operate with the representatives of an inspection company, to obtain representative samples of fresh concrete, for each 100 m^3 (130 yd^3) or fraction thereof, placed in one day. In no case, shall there be less that one test for concrete placed in any one day. Protect test cylinders as required.
4. A planned concrete pour must be made continuously without stopping. Conveying and placing equipment shall be such that when concrete placing has started, the depositing of concrete shall be at such a rate and of such sequence that the concrete is at all times sufficiently plastic to ensure proper bonding of successive layers or cells.
5. Concrete shall be conveyed to the place of final deposit by methods, which will prevent segregation or loss of material. Use concrete pumps to place concrete with approved methods, equipment and mix design.
6. Maximum time between adding mix water and complete discharge of concrete into the walls shall be 90 minutes.
7. Conveying and placing equipment shall be kept free from hardened concrete and foreign material and shall be cleaned at frequent intervals.
8. Concrete shall be deposited in the walls as close as is practicable to its final position to avoid segregation, voids and cold joints due to flowing and in approximately horizontal lifts to maintain a level surface.
9. While concrete is being placed it shall be consolidated thoroughly and uniformly be means of tamping and hand tools to secure a dense, homogeneous structure, and close bond with reinforcement. Internal vibrators shall not be used except under strict supervision and must not cause bowing of the wall surface.
10. Protect all freshly placed concrete from extreme heat, running water and mechanical shock for the duration of the curing period, 7 days minimum.

3.8 Cold Weather Requirements

1. All forms, surfaces and reinforcing steel with which the concrete is or is calculated to come in contact with, shall be heated to a temperature of not less than 4° C (40°F). De-icing chemicals shall not be used.
2. Use appropriate measures for protection and supplementary heating when required to ensure proper curing conditions in accordance with A23.3 or ACI 318 recommendations, if placement of concrete is carried out during periods of weather where temperatures are below the minimum specified by governing Building Codes for concrete.
3. All equipment needed for protection of concrete shall be on hand and ready to use before actual placing is started.
4. Clean walls using warm water during cold weather.

3.9 Tolerances

1. Variations from plumb: 6 mm in 3000 mm (1/4" in 10'-0")
2. Variations from plumb in any story or maximum: 13 mm in 6000 mm (1/2" in 20'-0")
3. Variations from level at tops of walls and sills and at head of openings: 6 mm in 3000 mm (1/4" in 10'-0")
4. Variations in the linear building lines from established position in plan and related position to columns or walls by others: 10 mm in any bay of 6000 mm (3/8" in any bay of 20'-0") and 13 mm in bays greater than 12000 mm (1/2" in bays greater than 40'-0").
5. Variations from specified elevation: 19 mm (3/4") at top of walls and 13 mm (1/2") at top of sills
6. Variations in sizes of openings: 13 mm (1/2")

3.10 Finishing of Concrete

1. All exposed surfaces at tops of walls and sills shall be finished with a wood float to an even, level surface.
2. At exposed surfaces, cut off projecting fins and fill all honeycombed areas using a bonding agent and a 1:2 cement sand mix or an approved proprietary patching compound.

3.11 Clean-Up

1. Upon completion of work, clear away from the building and site any excess or waste materials and debris and leave the premises in a condition acceptable to the Architect.
2. Clean and remove any concrete slurry from face of walls and leave walls clean and free of dirt and debris. Power wash the walls as per manufactures instructions provided in the Construction Guide.
3. Repair and patch any defective areas of wall face due to blowouts or breaking of webs using material and methods approved by the manufacturer. Patched surface shall be painted with approved paint to match the surrounding wall.

End of Section

Notes

Notes

We hope you found this guide informative while designing your project using RBS.

As always, our main goal at Royal Building Technologies is to ensure that our valued customers are 100% satisfied with our service and with Royal Building Systems™. Should you have any questions or comments, we would like to hear from you. You may contact us at the following:

Please visit the Technical Resource Centre section of our web site at www.rbsdirect.com for the latest version of this guide. Please forward us any suggestions or comments for improving this guide. All suggestions for improvements will be given full consideration for future revisions.

PURCHASER IS SOLELY RESPONSIBLE FOR DETERMINING THE SUITABILITY FOR USE OR APPLICATION OF ANY GOODS, INCLUDING COMPONENTS THEREOF, OR WHETHER SUCH GOODS MEET REQUIREMENTS OF APPLICABLE BUILDING CODES OR SAFETY CODES FOR SPECIFIC APPLICATIONS.

BUILDING SOLUTIONS LLC

Box 51 Sioux Rapids, Iowa 50585-0051
Phone: (712) 283-2541 Fax: (712) 283-2387

www.rbsiowa.com