A Case Study in City Design and Engineering with INTERLOCKING CONCRETE PAVEMENTS

Renovation of interlocking concrete streets and sidewalks in North Bay, Ontario.

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Revitalization of downtown and neighborhood business districts requires two important components in order to be successful: residents who provide business, and application of principles from successful suburban shopping malls. These principles involve improving the identity and function of business districts, which may include renovation of the streetscape with concrete pavers.

Other improvements to increase identity and function of business districts include enhancement of pedestrian spaces, parking, trees, and lighting. Districts can define their character through uniform store signage, renewal of store facades, and by moving overhead wires off the street. Shopping mall promotions applied to business districts can include district-wide advertising, seasonal promotions, cultural and civic events, and uniform store hours. All of these work together to attract shoppers.

This case study describes how concrete pavers were an essential component in unifying the identity of the central business district of North Bay, Ontario. It reviews how pavers were selected, the considerations involved in design and construction, and the results of an engineering evaluation after eight years of service.

The Setting

First explored in 1615 and founded in 1891, North Bay began as an outpost for fur trading. In the 1800's, North Bay emerged as a regional service center for lumber and mining activities in northern Ontario. Today, North Bay (pop. 56,000) sustains a steady flow of summer vacationers on Lake Nipissing and Trout Lake. The city lies 200 miles (330 km) north of Toronto, Ontario, with winters typical to those in southern Canada and the northern United States. Average seasonal temperatures range from a low of 0° F (-18° C) to a high of 75° F (24° C) (1).

Project Evolution

Like most cities, suburban shopping malls presented increased competition for shoppers in downtown North Bay. In the early 1980's, a plan was developed to create a new identity for the downtown area as part of replacing old utilities under the downtown streets. In 1982, David W. Cram and Associates Ltd., landscape architects of London, Ontario, submitted the successful bid on a proposal to renovate the center city (2). The project was part of a comprehensive plan to make the downtown more shopper-friendly (Figure 2).

During the planning stages of the project, a group of business operators called the Downtown Improvement Association required that the redevelopment meet three criteria. First, the project had to be completed as quickly as possible to minimize interfering with business. Second, vehicular and pedestrian accesses were to be maintained as long as possible during construction. Third, the completed area was to present the best image possible in order to attract more shoppers.

Figure 1. Unlike indoor shopping malls, business districts can be the stage for parades, large ceremonies, and civic events.

Durable, Winter–Resistant Concrete Pavers

About 105 in. (270 cm) of snow falls each year in North Bay. To keep traffic moving, the City of North Bay removes snow and ice every winter with snowplows, as well as with rock salt and sand. Main Street alone receives 300 tons (270 t) of salt each winter. (Figure 3) Interlocking concrete pavement was given first consideration because it had successfully performed around city hall for five winters under deicing salts. A genuine test of durability would be paving Main Street with concrete pavers crosswalks and ramps with colored units as permanent markings.

In order to withstand these conditions, the pavers were manufactured to meet requirements established by the American Society for Testing and Materials (ASTM) and the Canadian Standards Association (CSA). ASTM C 936, Standard Specification for Solid Interlocking Concrete Units, requires an average minimum compressive strength of

Figure 3. Main Street receives 300 tons of deicing salt each winter, plus sand for traction.

8,000 psi (55 MPa), less than 5% average absorption, freeze-thaw resistance of at least 50 cycles with no more than 1% loss of material, and resistance to abrasion testing. (3)

The CSA standard requires a compressive strength similar to ASTM C 936. However, the CSA standard has a freeze-thaw test that includes immersion of the paver test specimens in a salt solution. The test simulates the harsh conditions on streets during winter months from continuous presence of deicing salts. The CSA standard permits no more than 500 grams lost from the paver after 50 freeze-thaw cycles. (4) This is approximately 1% loss of material.

Figure 2. The designer's rendering characterized a renovated North Bay with concrete pavers.

Pavement Structural Design

The downtown project covers more than 150,000 square feet (14,000 m^2) of streets and sidewalks. The pavement design was based on a 20-year life. Main Street traffic consists of approximately 8,000 vehicles per day with 5% delivery trucks and buses. The sidewalks included 2.375 in. (60 mm) thick pavers on 1.2 in. (30 mm) of bedding sand. The base under the pavers was 6 in. (150 mm) of compacted aggregate.

Figure 4 illustrates the pavement cross section for the street which includes 3.125 in. (80 mm) thick concrete pavers over 1.2 in. (30 mm) of bedding sand. A 6 in. (150 mm) aggregate base (Ontario A) and 8 in. (200 mm) subbase (Ontario B) was compacted over free draining, sandy soil subgrade with shattered rock or bedrock. The California Bearing Ratio (CBR) of the subgrade was estimated to be between 10 and 12 percent. Surface water flows to catch basins and storm sewers.

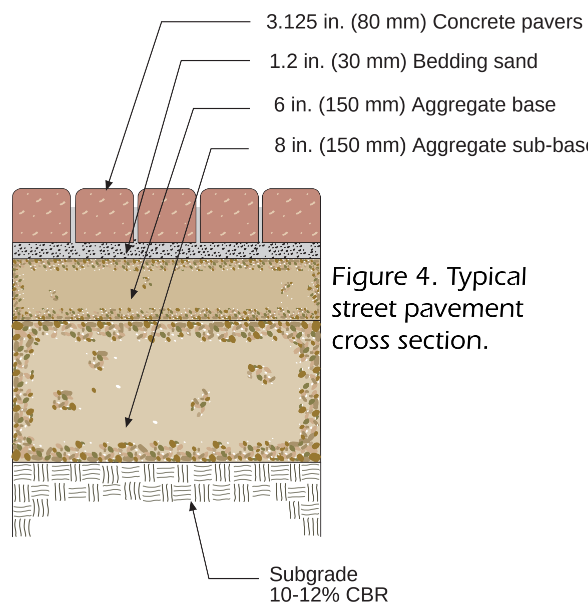

Figure 4. Typical street pavement cross section.

Total Project Cost (1984)

Cdn $3.0 million, includes paving, landscaping, utilities, reconstruction, and professional fees

Figure 5. Compaction of the base is essential to all flexible pavements including those built with concrete pavers.

Timely and Quality Construction

Construction began in 1983 by removing and replacing existing utilities with new ones, and by placing overhead wires underground. Small, temporary bridges allowed pedestrians to maneuver around construction activity. New light standards and street furniture replaced old ones.

In constructing the streets, the subbase and base were compacted and the density of the base material was checked regularly with a nuclear density gauge (Figures 5 and 6). This helped ensure 100% modified Proctor density. As with any flexible pavement, monitoring density of the base to achieve a specified level of compaction is critical to the long-term performance of interlocking concrete pavements.

All interlocking concrete pavements require edge restraints to prevent lateral creep. For the North Bay project, cast-in-place concrete curbs were used. In addition, the curbs also established grades for the finish elevation of the pavement. Concrete collars were cast around utility structures to secure the iron frames. The collars provided a stationary restraint for the concrete pavers (Figure 7).

Figure 6. Monitoring of base compaction during construction minimized the likelihood of settlement later.

Figure 7. Concrete collars protect utility structures.

Figure 8. A herringbone pattern in the street provided resistance to turning,

Figure 9. A crown in the road contributes to interlock by allowing the pavers to settle and tighten slightly under traffic.

Figure 10. A plate compactor seats the pavers in the bedding sand.

Figure 11. Sand swept into the joints and compaction of the pavers transform the pavement from a loose collection of units to an interlocking load-bearing pavement system.

A herringbone pattern in the streets offered the greatest degree of interlock for the pavers (Figure 8). A slight crown in the road for drainage also contributed to interlock, strengthening the pavement as the pavers settled slightly from traffic (Figure 9). After the pavers were placed in a herringbone pattern, they were compacted with a plate compactor. The force of this machine moves bedding sand into the joints between the pavers and begins interlocking of the units (Figure 10). After an area is compacted, sand is swept into the joints and the pavers are compacted again until the joints are completely full of sand (Figure 11). The compacted pavers with sand-filled joints interlock so that vehicular loads are transferred from one paver to the next.

The chairman of the Business Improvement Area in North Bay reported that downtown business decreased during construction, but not to the degree expected. Once work was completed, business activity exceeded preconstruction levels. Many of the businesses made major improvements to the facades of their stores in order to help maintain an up-market image and a steady flow of customers.

Figure 12. Rut depth measurements after eight years of traffic showed rutting to be slight.

Pavement Evaluation

In 1991, approximately eight years after the completion of the project, a detailed condition survey and nondestructive deflection testing of the pavement were conducted by PCS/LAW Engineering of Beltsville, Maryland, an independent consultant (5)(6). The condition survey included pavement rut depth measurements, and a distress survey with deflection testing using a falling weight deflectometer.

Small Rut Depths

Some 230 measurements of wheel rut depths were taken from the curb to the centerline along Main Street (Figure 12). Average rut depths were 0.22 in. (6 mm), much smaller than the 0.5 to 0.75 in. (13 to 19 mm) depths considered as failure by most highway agencies.

Minor Pavement Distress

The survey identified distress types, measured their severity, and the total area affected by each type of stress. The entire pavement was divided into sections, randomly sampled and stresses recorded. The total sampled area equaled 57,600 sq. ft. (5,350 m^2). The pavement distress types measured are listed in Table 1.

About 4% of the pavement surveyed had depressions concentrated in an area that had been reinstated after utility repairs, and where the base was not replaced properly. According to the report by PCS/Law Engineering, the pavements "are providing excellent performance… surface deformation occurs in less than 1.5% of the pavement areas surveyed." The report concludes that after eight years, the pavers are "still in very good to excellent condition."

Table 1—Summary of Visual Distress After Eight Years of Service

Distress Type	Percent of Area
Surface Irregularities	
Rutting (extreme)	0
Swell/heave	0
Depression	4.17
Transition to utility	0.07
Transition to curb	0.09
Paver Distress	
Corner of edge spalling	3.59
Cracked pavers	0.12
Snow plow damage	0
Joint Distress	
Deformed joints	0.07

Structural Performance Exceeds Asphalt

Structural evaluation was made with a falling weight deflectometer (FWD), a testing machine that simulates the small but rapid deflections of pavements under moving vehicular loads. A Dynatest FWD mountedon a trailer applied impulse loads of 5,000 to 9,000 pounds (22 to 40 kN) to 242 locations on Main Street (Figure 13).

Pavement layer moduli (a measure of pavement stiffness based on applied stresses and resulting strains from deflection loads) were calculated using a computer program. The program modeled a three-layer structure: a 4.125 in (105 mm) thick composite of concrete pavers and bedding sand as a single layer, the 14 in. (350 mm) thick crushed aggregate base and subbase, and the soil subgrade. Average pavement layer moduli are shown in Table 2.

Figure 13. A falling weight defectometer was used to evaluate the structural capacity and remaining life of the pavement.

The deflection testing showed the pavement to be stiffer in the intersections than in the streets. This is due to interlock increasing as the pavers receive traffic over time. The moduli in Table 2 equal or exceed an equivalent thickness of a hot mix asphalt pavement. Considering that the stiffness (elastic modulus) of asphalt decreases substantially in warm temperatures, interlocking concrete pavements can provide superior structural performance in such conditions.

The structural testing demonstrated that the life remaining in the pavement exceeds 20 years, assuming that future traffic loads remain constant. Furthermore, the engineering report noted that unlike asphalt, concrete pavers "will not deform internally and will not crack from fatigue."

No Maintenance

Maintenance records were reviewed since the installation of the pavement. No maintenance had been performed on the pavement in twelve years. This is remarkable performance for a pavement subjected to such severe winter conditions as freeze-thaw, deicing salts, and snow plows. With their compressive strength, low water absorption, and durable aggregates, concrete pavers can withstand degradation from salts, abrasion from sand, and still remain in service. Asphalt or concrete roadway pavements have not endured degradation from frost heaving, temperature extremes, traffic, sand and deicing salts as well as concrete pavers.

North Bay's Director of Transportation and Works, Brian Baker, P. Eng., confirms that no maintenance has been required. "The interlocking concrete pavement has performed exceptionally well against many seasons of ice, snow, sand, and deicing salts. The superior performance can be credited to the pavers and installation meeting industry standards." Mr. Baker was responsible for the design and construction of the entire project.

Figure 14. Success breeds success: concrete pavers at the North Bay train station.

Unlike conventional monolithic pavements, concrete pavers are modular, enabling access to repair of underground utilities without damage to the pavement surface. After removal and repair, the same pavers are reinstated without patches. Furthermore, pavers can tolerate minor subgrade settlement without cracking while still maintaining a continuous riding surface.

	Location			
Pavement Section	Streets		Intersections	
	Ksi	MPa	Ksi	MPa
Pavers & bedding sand	377.0	8,568	559.9	12,704
Aggregate base & subbase	39.5	898	28.7	652
Subgrade soil	14.9	339	17.9	407

Table 2—Average Pavement Layer Elastic Moduli

Conclusion

The performance of interlocking concrete pavements in North Bay has been exceptional. Maintenance to date has been virtually nonexistent. Rutting in the wheel paths is limited and the area of pavement showing distress is minimal. The structural capacity of the pavement will likely exceed 20 years. The excellent performance of the pavement can be credited to high quality concrete pavers and proper installation.

Since the downtown was renovated, the city has continued using concrete pavers in public places such as sidewalks, boulevards, the train station, and lengthy promenades along Lake Nipissing Waterfront Park (Figures 14 and 15). The investment in interlocking concrete pavement by the City and citizens of North Bay, Ontario, is being returned through its performance as an engineered pavement, plus enhanced character and function.

Figure 15. A promenade along Lake Nipissing in concrete pavers.

References

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Pavement design will vary with the traffic, soils, climate, local construction materials and methods. A qualified civil engineer should always be consulted to determine cost-effective designs for durable, low maintenance applications of concrete pavers.

Owner:
City of North Bay, Ontario

Project Management:
City of North Bay, Department of Engineering

Project Engineers:
Northland Engineers & Planners, North Bay, Ontario

Project Architect:
David W. Cram and Associates, Ltd., London, Ontario

General Contractor:
Duntri Construction, Oshawa, Ontario

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

1444 I Street, NW–Suite 700
Washington, D.C. 20005-6542
(202) 712-9036
Fax: (202) 408-0285
E-mail: ICPI@icpi.org
Web site: www.icpi.org

In Canada
P.O. Box 23053
55 Ontario Street
Milton, Ontario L9T 2M0