

# The potential use of stainless steel in concrete highway joints

B. R. Leslie, B. H. Neuhart

*The use of steel dowel bars has been a basic design practice in most United States' Departments of Transportation for many decades. These bars transfer loads across sawed or formed transverse joints from one concrete pavement slab to another, while permitting expansion and contraction movements of the concrete. As the highway system has aged, the doweled bar pavement joints have shown many problems. These often stem from corrosion of the steel dowel, which causes the bar to be frozen in the joint and in the surrounding concrete thus locking the joint. This transfers the concrete movement stresses to the concrete itself where cracking and spalling eventually lead to joint failure.*

*To address this corrosion problem and extend the serviceable life of the joint, stainless steel has been suggested as the material of choice.*

## INTRODUCTION

Dowel bars are straight pieces of steel, 1\_ inches (38 mm) in diameter by approximately eighteen inches long (457 mm). They are inserted at the midsection of highway concrete slab ends about 12 inches (305 mm) apart and act as a load transfer device when traffic moves from one slab to the next. The bars also permit expansion and contraction movements during curing and climactic changes during the lifetime of the slab. Currently these bars are commonly made from mild steel. It is well known that mild or "black" steel corrodes and is subject to failure in high chloride environments. A comprehensive study of the history of highway joint construction, load and stress calculation and a major literature survey has been presented by Moore (1) of the University of Kansas. The use of dowels as a load transfer device became widespread during the 1960s. At that time a large expansion of the U.S. highway system was undertaken with much of the new pavement constructed as rigid joint pavement (RJP).

The need for load transfer devices that were durable was well recognized by highway design engineers given the type of joints being used. Dowel bars have continued to be used since the 1960s with many efforts made to improve their longevity and protect them from corrosion damage. Kelleher and Larson (2) of the Federal Highway Administration (FHWA) reported in 1989 that the most effective bars for longtime performance were solid bars of stainless steel or a stainless sleeve tight over a black bar. Stainless clad bars have been intermittently evaluated, but have not found widespread acceptance. Plastic coatings, epoxy coatings and various fiber-glass formulations have also been used. Sealers, membranes and other protective methods for the joint have also been tried. The U.S. highway interstate system is now some forty years old and new construction methods are actively being sought by the FHWA and State engineers to extend the life of new highways.

Mild steel and even epoxy coated steel will rust (oxidize) when exposed to corrosive conditions and particularly so in high chloride situations. When this occurs, the oxide formed is several times the volume of the original metal. This volume increase leads to internal stresses in the concrete

with resultant spalling and cracking of the concrete. Stainless steels do not oxidize in this manner even when subjected to extreme chloride environments as has recently been shown by a FHWA study conducted by Wiss, Janney, Elstner of Illinois. (3) Due to its corrosion resistance no deterioration of the surrounding concrete occurs. In the case of dowel bar, the failure mechanism comes with the oxidation of the common steel that locks the bar in place, restricting the normal transfer of the load. Stresses become transferred to the concrete itself and breakage and cracking in the joint become prevalent. Use of stainless steels would eliminate this cause of joint failure.

## PERFORMANCE ISSUES

There are two types of joints: transverse contraction joints and transverse expansion joints. Pavement joints are constructed in new pavement (Figure 1) to accommodate one or more of several possible movements. While the new concrete is curing, the hydration process causes the pavement mass to contract and shrink. The presence of transverse contraction joints at strategic longitudinal intervals (generally 12 to 20 feet or 3.7 to 6.1 meters prevents the development of random cracks in the slab. Cured and mature concrete slabs respond to changes in ambient temperature and radiant heat from the sun by expanding and contracting. These movements are accommodated in part by the doweled joint where at least one end of the embedded dowel is treated with a debonding agent and is free to slide longitudinally within the concrete.

Adjacent to structures and at other strategic locations, where pressure from adjacent pavement slabs could be highly damaging, expansion joints are constructed with a full depth opening width of three inches (76mm) and filled with a pre-formed compressive material. The dowels in the expansion joint are fitted with hollow caps to provide a recess into which the dowel can slide as the expansion joint closes.

Problems can occur in these systems when the mild steel dowel corrodes. The oxide surface of the dowel bar expands and "locks" the dowel into the surrounding concrete, thus transferring any longitudinal movement stresses to the concrete which then fails in either tension or shear mode. The failure process once begun is often progressive. As the cracked concrete admits more moisture and chloride-laden road salts, the corrosion of the dowel increases and the concrete disintegrates further. Consequently, the joint weakens and fails.

Brian R. Leslie, Bernard H. Neuhart,  
Specialty Steel Industry of North America

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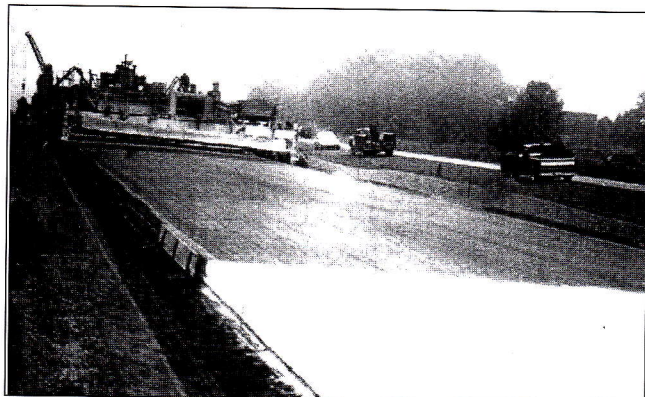


Figure 1: New Concrete highway being constructed.

### THE MARKET DEVELOPMENT PROGRAM

The Specialty Steel Industry of North America (SSINA) began a market development program to increase the recognition of stainless steel in North America in 1992. SSINA has sponsored several programs in the past six years to demonstrate the desirability and viability of stainless steel in applications where corrosion and deterioration of metal components has been a problem. It should be noted that the cost of corrosion in the United States alone has been estimated to be as high as 300 Billion dollars on an annual basis. If corrosion resistant materials such as stainless steels were to replace existing (black steel, low alloy material, galvanized, etc.) metal components, fully one third of the total cost (100 Billion dollars) could be saved.

Stainless steel is currently being tested and used in such applications as bridge deck reinforcement. (4) Studies such as the Wiss, Janney study as well as several European and UK studies have shown stainless can and does resist, to a far greater extent than black or epoxy steels, the corrosion caused by high levels of chlorides. The chlorides often build up over time to high levels (3-5%) due to absorption and or cracking of the concrete exposing the reinforcing steel to corrosive conditions.

The SSINA approached the Highway Innovative Technology Evaluation Center (HITEC) to establish a program for the evaluation of stainless steel as dowel bars. HITEC was established by the Civil Engineering Research Foundation (CERF) through a grant from the Federal Highway Administration to encourage and expedite the introduction of new technologies to the highway program.

The stainless steel market development committee of the SSINA applied for and received acceptance from HITEC of an evaluation plan for stainless steel dowel bars. The Plan is composed of three parts: a literature review, field installations, and laboratory investigations. It also provides for extensive follow-up inspection and evaluation of the field sites. The principle thrust of the HITEC evaluation will be in the observation and field testing in five mid-west states that have agreed to install highways slabs using stainless steel. These installations will use stainless steel, either in tubular form or as solid bar, as the dowel bar connectors between slabs. These states are Illinois, Iowa, Kansas, Ohio and Wisconsin. Several other states such as Pennsylvania and Virginia also have separate evaluation programs using stainless to upgrade the dowel bar performance.

Several American Universities and their Civil Engineering departments are also actively involved in the evaluation of the field installations and are working with the various state DOTs. This includes Marquette University (Wisconsin) and Iowa State University (Iowa). Initial monitoring of the HITEC test sections is being done by university and state

DOT personnel upon completion of the installations and at six month intervals for the first 18 months of the service life. Annual monitoring will continue at one-year intervals thereafter for a total time of five years. In addition to pavement condition observations, load transfers will be measured using falling weight deflectometer and verification of the dowel bar positions will be verified using ground-penetrating radar. A second and concurrent part of the field installation will be joint condition assessment, deflection testing and the coring of previous state experiments on dowel bars. Several U.S. states had small evaluation programs in the 1980s, notably Pennsylvania, New Jersey and Ohio. In the case of Ohio, several dowel bar installations were done using a 200 series stainless steel generally known in the U.S. as Nitronic 33.

A third and final part of the field program will be the removal of dowels from the field sites and a laboratory evaluation at the end of the five-year period. Other laboratory investigations on samples of stainless steel will include dowel bar fatigue, dowel debonding and pull out stress determinations, dowel durability and load transfer capability using shear tests.

### DETAILS OF TEST MATERIALS AND FIELD INSTALLATIONS

Stainless steel material used in this program have included both solid stainless bars and stainless tubing filled with a grouting compound (Master Builders Grout 928). Both products are expected to perform well in laboratory and field investigations, however, the welded tube is expected to be more cost competitive with the mild steel bars currently being used. Most of the installations were performed in the summer and fall of 1997 and interim test reports should be available in early 1999 from both Wisconsin and Iowa. The final installations for Illinois and Kansas are expected to be complete in early 1999. Table one gives a listing of the location, approximate size of the installation and its current construction status. Via the HITEC program, the State DOTs and universities involved have shown excellent cooperation in moving the program forward.

In the United States, various methods are used to position the dowel bar at the slab joint. A Basking technique where the dowel is positioned in a wire basket assembly and the concrete cast over it is one method. This technique was used in the Iowa and Ohio installations. Another method is by use of injection equipment. In this case the bars are automatically dropped into position across the width of the slab and the dowel bar is forced into the concrete to its desired depth by a hydraulic activated ram. This methodology was used in the Wisconsin installation, which is by far the largest of the field trials. Some 1000 solid bars and approximately 600 grout filled tube were installed on Route 29 both east and west of the city of Wausau, Wisconsin. Figures 2 through 7 show pictures of the injection method used to position the dowels 135 mms. below the concrete surface. Total depth of the slab in this installation was 11 inches (279 mm).

Tables 2 and 3 give a summary of the mechanical and chemical properties of the materials used in the Wisconsin installation. All material was 304L stainless steel. Some states and FHWA personnel have also expressed interest in using an even higher corrosion resistant stainless such as 316L and /or duplex 2205.

Table 4 gives a summary of the tests and observations expected from each state as a part of the test program. Preliminary reports and data are expected to be available in the first quarter of 1999 from Iowa and Wisconsin, as is certain data from Marquette University. The longer-range aspects of the evaluation is expected to be most critical in the overall process, since stainless steel's main benefit is long term cor-

Table 1  
Summary of Installations  
by State.

State	Installation Size	Location/Status
Iowa	13 joints on 8 inch centers and 23 joints on 12 inch centers	US Route 65 South East of Des Moines, Iowa- Complete
Wisconsin	Approximately 100 joints with both solid bar and grout filled welded tube	US Route 29- Two locations east and west of Wausau- Construction complete
Illinois	10 joints - 24 bars/joint	Route US 16, West of Springfield- Spring 1999 Construction
Kansas	To be determined	To be announced
Ohio	12 Joints	Athens, Ohio-Complete

Table 2  
Summary  
of Mechanical Properties  
(Wisconsin)  
304L Stainless Bar  
and Welded Tube.

Product	Hardness Rockwell B	Yield Strength (Ksi/Mpa)	Ultimate tensile Strength (Ksi/Mpa)	Per cent elongation	Per cent Reduction in area
Solid bar(38mm)	86 HRb	47.6(328)	94.4(651)	60	73.7
	81 HRb	41.7 (288)	94.6(652)	58.4	74.7
	86 HRb	40.6 (280)	94.9 (654)	58.1	75.4
	83 HRb	47.2 (325)	94.2 (648)	53.2	75.0
Tubular Product	84 HRb	43.2(301)	88.9 (624)	54	

Bar data courtesy of Avesta Sheffield, Richburg, South Carolina and Slater Steels, Fort Wayne, Indiana Tubular sheet data- Courtesy of Bishop-Damascus Tube, Greenville, Pa.

Table 3  
Summary  
of Chemistry Results  
(Wausau, Wisconsin,  
Route 29, Installation).

Product	%C	%Mn	%Si	%Cr	%Ni	%Mo	%N
Solid bar	.02	1.62	.52	18.14	8.11	.31	.07
	.02	1.69	.40	18.43	8.14	.22	.07
	.02	1.60	.40	18.25	8.12	.24	.06
	.02	1.79	.43	18.37	8.81	.54	.08

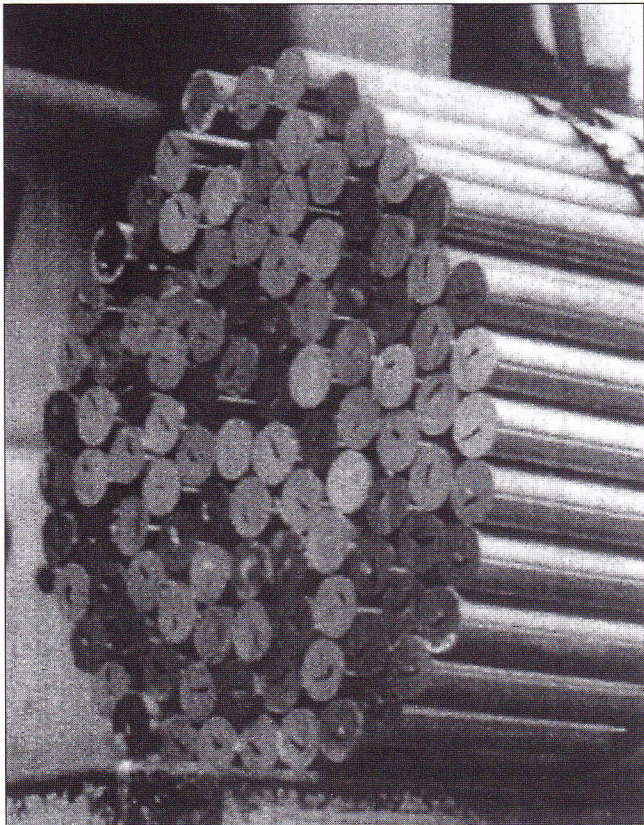


Figure 2 Bundles of 304L stainless steel dowel bars on loader.

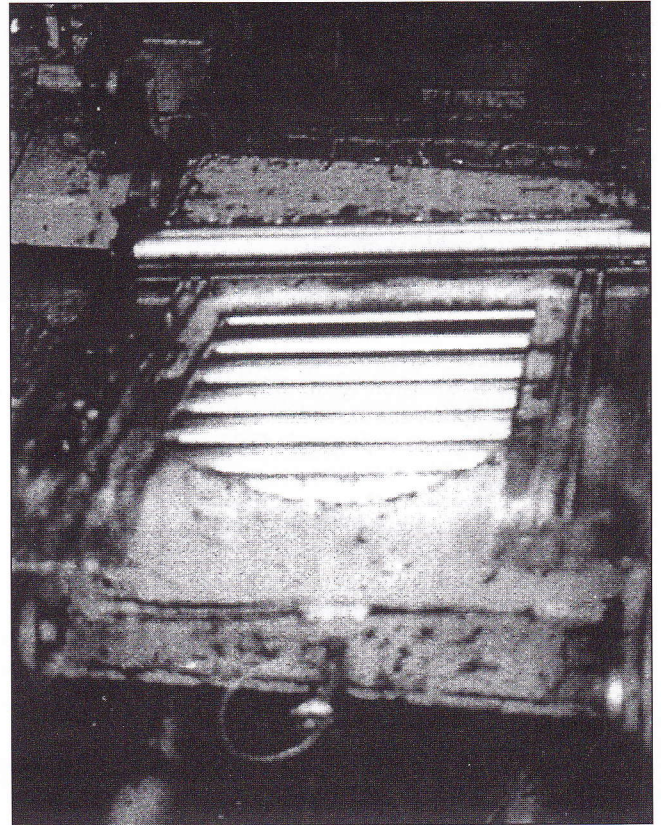


Figure 3 Bars being rolled out on injection cart.

Table 4  
Summary of plan, schedule, sites and tests for field program FRP and stainless steel sowel HITEC evaluation (April 27, 1998).

Location	Timing	Materials	Sites/Sizes	Test/Observations
Illinois	1997	FRP	5 sections: 1 @ 450'	Constructions costs & features FWD load transfer Faulting
	1998	Stainless & FRP	7 sections 5 @ 150' 2 @ 450'	Dowel position check Concrete cracks & spalls Traffic loading data
Iowa	1997	Stainless & FRP	FRP - 4 sections: 2 @ 450'; 2 @ 100' Stainless - 2 sections 1 @ 220'; 1 @ 520'	Constructions costs & features FWD load transfer Faulting Dowel position check Concrete cracks & spalls Traffic loading data
Kansas	10/01/97	FRP	106 joints constructed over a length of 1600' 24 joints were FRP	Constructions costs & features FWD load transfer Faulting Dowel position check Concrete cracks & spalls Traffic loading data
Ohio	10/16/97	Stainless & FRP	6 joints, ea mat'l	Constructions costs & features FWD load transfer Faulting
	Spring '98	Stainless & FRP	6 joints, ea mat'l	Dowel position check Concrete cracks & spalls Traffic loading data
	Fall '97	Stainless & FRP	1983 & 1985 Installations	FWD tests at joints GPR dowel position verification Inspection of joint conditions Core 3 dowels, each mat'l and cutout 3 full dowels, each mat'l at each site
Wisconsin	Fall '97	Stainless & FRP	2 sections @ 600' ea with chairs for placement	Constructions costs & features FWD load transfer Faulting GPR dowel position check Concrete cracks & spalls Traffic loading data
	Fall '97	Stainless & FRP	2 @ 4000' ea with DBI for placement	Constructions costs & features FWD load transfer Faulting GPR dowel position check Concrete cracks & spalls Traffic loading data
Each experiment section	After 5 years	Stainless & FRP	As installed	FWD tests at joints Inspection of joint conditions Core 3 dowels, each mat'l and cutout 3 full dowels, each mat'l at each site

Note: Epoxy-coated mild steel dowels will serve as the control on all projects.

rosion resistance. As corrosion may not be prevalent on mild steel bars in the short term, differences in joint performance are not expected to be statistically significant until at least three to five years exposure in field conditions.

### REPORTS

A stand-alone report will be published by HITEC at the conclusion of the initial 18-month observation period. (Tentatively fall 1999) This report is expected to cover the following aspects:

- Experiment design and construction data
- Dowel placement verification
- Field construction observations
- Initial load transfer performance
- Initial joint condition observations
- All completed laboratory analysis

At the end of five years, a report will be written to include the following:

- An executive summary of the eighteen month report
- Joint condition and dowel performance data for the full five year period
- All laboratory test results and analysis
- An analysis of potential Life Cycle Cost(LCC) for the use of stainless steels versus mild steel

### MARKET POTENTIAL

A study was commissioned by HITEC and SSINA to estimate the market potential for dowel bars in RJP. Porter and Braun (5) reported on this in 1997 via an Iowa State University report. Based on an assessment of the state of Iowa and various other state and FHWA studies regarding the percentage of RJP versus other highway systems of construction,

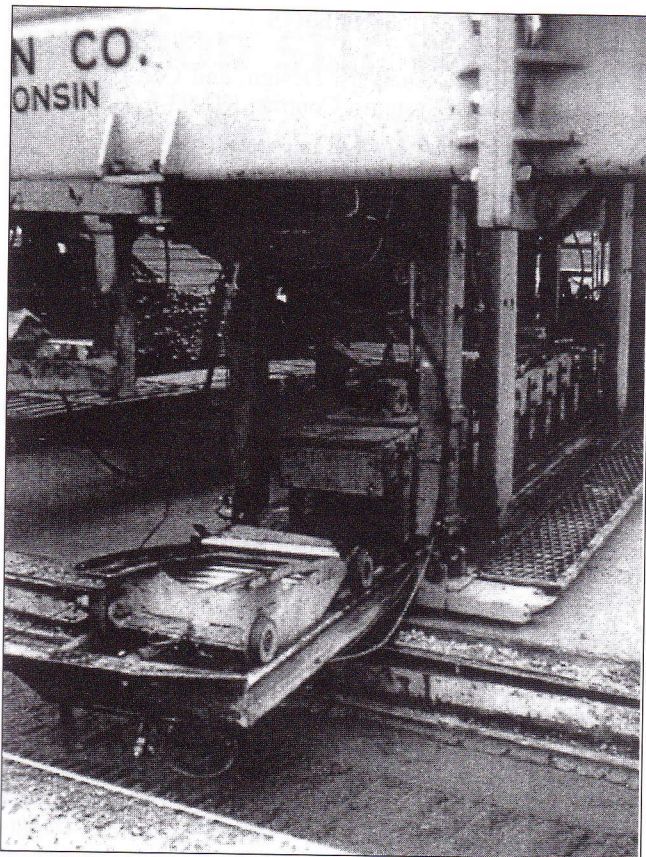


Figure 4 A wider view of the injection cart.

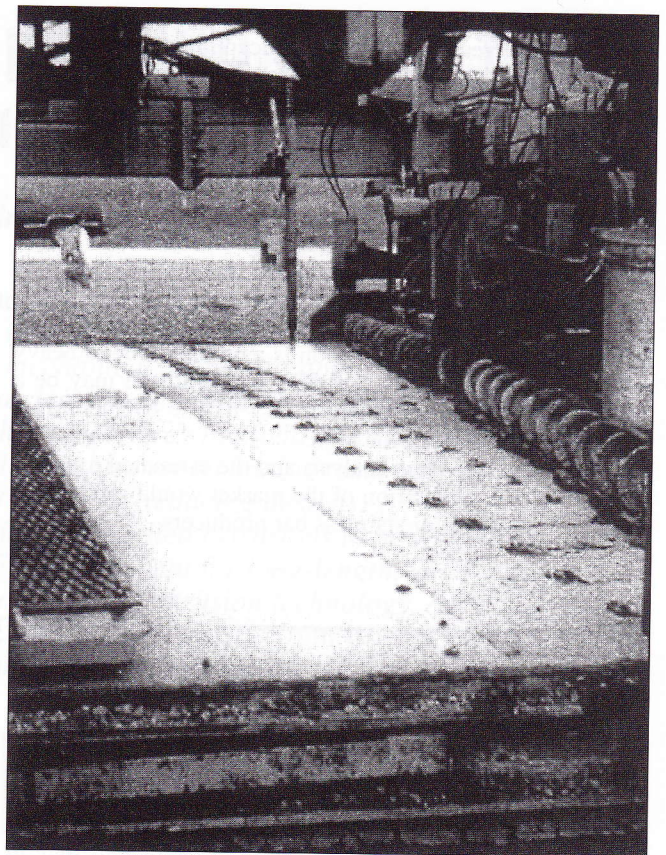


Figure 6 Bar pattern of insertion showing distribution across the slab and width of highway.

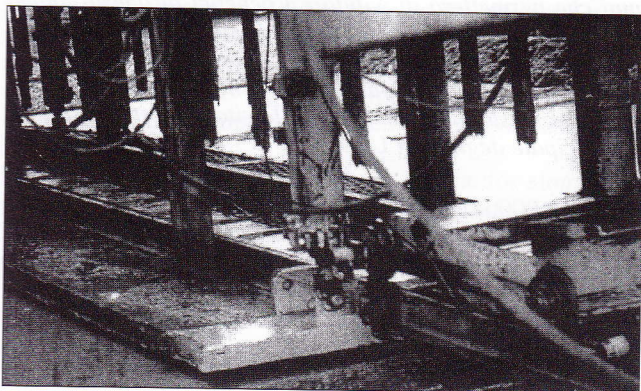


Figure 5 Bars being injected into highway 29 near Wausau, Wisconsin.

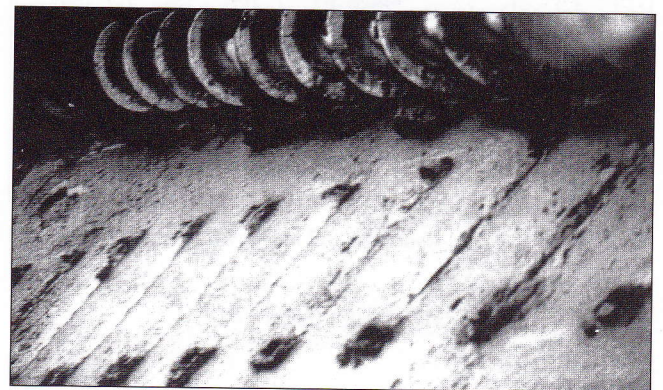


Figure 7 Concrete surface being smoothed over by injection apparatus after bar insertion into slabs.

they estimated the amount of RJP construction in Iowa as follows:

Estimation 1997	Functional Systems			
	Primary roads	Secondary	Airports	Total
Square yards	2,130,000	245,000	50000	2,425,000

Assuming a lane width of 12 feet (3.63 Meters), a slab length of 22 feet (6.6 meters), one joint per slab and 12 dowels per joint, an estimated usage for Iowa exceeded one million dowels. Projecting in similar fashion and making adjustments for states with little RJP use, and discounting states with climates substantially milder than those states where dowel bar corrosion was a problem in joints, they projected a usage as follows:

Estimate	Dowel PCC Pavement* Square yards per year	Estimated Required Dowels
Iowa	2,425,660	1,100,000
USA	40,850,000	18,500,000

\*Portland Cement Concrete

It should be noted these are approximate numbers. Several states are experimenting with selective placement of dowels concentrated in the wheel path of the highway lane with much reduced usage in other areas of the joint.

With an aging highway system, some market for replacement dowels might be expected. However the rehabilitation of joints in older highways is often cost prohibitive since it is labor intensive. The most effective methodology is often total slab replacement. The market for replacement bars is estimated at perhaps 5% of the total market for new construction.

Since alternative materials such as stainless steel have a substantial cost increase at the project inception, the consideration of life cycle costs is vital for justification of the use of more expensive materials. Unfortunately in many cases good data does not exist in many State Departments of Transportation (DOTS) to identify the direct cost of joint failures. However, much effort is being expended in the U.S. to increase the life of the concrete by use of high performance concrete, sealers, membranes, concrete additives, etc. From a design standpoint, it would also be prudent to attempt to improve the life of the joint system to prevent premature failure of the concrete from damage to the joint interface. In certain locations where corrosion is a problem due to heavy salting or where particular grading and drainage may be a problem, stainless may easily justify its use by increasing the overall longevity of the joint.

Based on the Iowa State analysis and the estimated usage of RJP even a 5% penetration of the market would represent a significant tonnage for stainless bar producers.

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- 4) NEUHART, B. H., Use of Stainless Reinforcing Bar-Status 1998, Proceedings of the International Conference on Concrete Reinforcement, Orlando Florida, December 1998
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A B S T R A C T

**LE POTENZIALITA' DI IMPIEGO DELL'ACCIAIO INOSSIDABILE NELLE GIUNZIONI DEI VIADOTTI IN CEMENTO**

*Per molti decenni l'impiego di dowel bars ha rappresentato una pratica fondamentale di progettazione per la maggior parte dei Dipartimenti dei Trasporti negli Stati Uniti. Queste barre trasferiscono, da una lastra di pavimentazione in calcestruzzo ad un'altra, i carichi attraverso i giunti trasversali, consentendo movimenti di espansione e concentrazione del calcestruzzo. Con l'invecchiamento del sistema stradale, i dowel bars hanno evidenziato molti problemi, spesso derivanti dalla corrosione del perno di acciaio, che porta al blocco della barra all'interno del giunto e del calcestruzzo circostante e quindi all'irrigidimento del giunto. Questo trasferisce le sollecitazioni del movimento del calce-*

*struzzo al calcestruzzo stesso, nel quale si formano cricche e scheggiature che portano alla rottura del giunto. Per risolvere questo problema di corrosione e per prolungare la vita del giunto, è stato suggerito l'uso di acciaio inossidabile. A tale scopo si sta effettuando un importante programma per l'analisi dei tubi in acciaio inossidabile e delle barre impiegate come dowel bar. Il programma è molto completo e comprende installazioni in campo e un programma di verifiche da condursi nel tempo. E' prevista una durata di cinque anni che permetterà di valutare i benefici di questa nuova applicazione dell'acciaio inossidabile sul lungo termine. Lo studio dovrebbe fornire dati e informazioni importanti, compresa l'applicabilità dell'acciaio inossidabile in termini di costi, in vista di un aumento della vita del sistema stradale principale degli Stati Uniti.*