adequate welds, fabrication, or drilled-in anchorages initiate and aggravate vibrational damage. Improperly placed bolts, plates, angles, or seals of expansive devices are easily damaged or sheared off by snowplows, other maintenance equipment, and heavy commercial traffic loads.

Remedial actions. Loose connections and inadequate anchorage generally cause a joint device to vibrate under traffic. In such cases the joint device and anchorage system surrounding the damaged area should be removed and replaced. Joint devices damaged by accidents are either modified in the field to make them secure or are replaced.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are drawn from the evaluation of expansion devices in Minnesota.

1. Joint devices and glands must be continuous and not segmental.
2. Concrete material should be used on either side of the expansion device and the joint should be sealed between the device and the concrete.
3. The expansion joint device should be recessed 0.25 to 0.5 in. below the adjacent concrete.
4. Snowplow guards for glands should be added on expansion devices placed at 20-degree or greater skews. Three-eighths steel bars placed out of wheel tracks will work adequately.
5. Claws of expansion device must hold the device securely. Bolted down claws generally loosen up and allow the gland to easily pull out.
6. Devices must be protected with a coating such as galvanizing.
7. Routine bridge maintenance should include cleaning the gland out and minor repairs to the gland.
8. Cast-in-place plate anchorage systems hold the device securely during construction and in service. Drilled-in anchorages work loose and expose the device and gland to potential damage.

Specification Writing for Bridge Deck Joint Sealing Systems

GUY S. PUCCIO

ABSTRACT

In this paper a simple way to write specifications for expansion joint systems, so as to obtain an economical system with good performance characteristics, is demonstrated. The purpose of the paper is to bring to the design engineer's attention aspects of contract documents that, if not properly handled, can result in controversy or cost overruns. It is demonstrated that if the specifications clearly describe the desired expansion joint, and if the contract drawings show its characteristics and physical requirements and show how it is to be installed, then the right expansion joint can be obtained at the right price through competitive bidding.

The first breakthrough in the development of a satisfactory sealed expansion joint occurred in the early 1960s through the introduction of the elastomeric compression seal. Since then, many alternative expansion joint systems have been available for sealing expansion joints in bridges.

The proprietary nature of these systems made it difficult, if not impossible, to write a universal, meaningful specification. Also, some of the expansion joint systems were failing within a short period of time after installation.

In the quest for improving the performance of expansion joint systems, the Transportation Research Board funded a project to study criteria for developing specifications. Subsequently, a report was written suggesting various criteria for a performance specification. Initially, "segmented seals, bolted to the bridge deck, subjected to varying degrees of tension and compression" and having a moment range of 2 to 4 in. (1) were addressed in the report.

The basic premise was to test these expansion joints as a system in the laboratory and evaluate the results. The systems would be put through several thousand cycles of various testing procedures, which included flexing, impact loading, skew racking, leakage evaluation, and so forth. If the system did not exhibit signs of deterioration or fatigue due to stress and maintained its watertightness, it would be accepted for use in the project.

However, the described tests are valid only when applied within the context for which the report has been written. The report promoted a performance specification that would test tension-compression type solid elastomeric expansion joint systems, the deficiencies of which are well understood.

On the other hand, when applying these criteria to other types of systems, the specification requirements relegate the tests to a material evalua-

tion. For example, applying the cycling concept (e.g., flexing a strip seal 10,000 cycles) will not determine whether a particular system will give satisfactory performance; if a particular rubber material specified were capable of being flexed tens of thousands of times, there would be no need for this test.

Another point is that there must be a discernible engineering difference in or a modification of the use of the joint material specified in order for it to react differently from what could reasonably be expected.

What is being suggested here is that joint systems of like engineering design parameters that are manufactured from identical materials will behave in a similar fashion. Thus engineering education and experience can be used in evaluating and comparing various manufactured expansion joint systems for their conformity to a given specification or their subsequent likelihood of satisfactory performance.

Because there are ample data on physical and mechanical properties of engineering materials, a performance specification of the nature discussed becomes redundant after the initial test, and it becomes cumbersome to administer as well as needlessly restrictive and expensive to the ultimate user.

A side effect of this form of testing is the erroneous premise "more or greater is better." Engineers have adopted criteria for specifying expansion joint systems without field testing or other bona fide documentation as to either their validity or need. Certain requirements have recently evolved that have no real engineering significance other than relating to a given physical parameter chosen by a specifier.

If an expansion joint has been subjected to field performance evaluation and it is constructed of known engineering materials, there is no cause to eliminate the expansion joint from consideration for the sole reason that it has not met an arbitrary physical parameter.

The purpose of this paper is to demonstrate a simple way to specify expansion joint systems in order to obtain an economical system with good performance characteristics.

To begin with, specifications are only a part of the contract documents, and the engineering plans and the proposal are equally important in conveying information to the bidder and to the inspection forces, including the owner's engineers. It is proper use of all these instruments that provides the intent of quality expected. How the design engineer uses his or her knowledge of the subject and combines known parameters within contract plans and specifications is what in essence will determine the type and quality of expansion joint system ultimately incorporated into the project.

GENERAL

The design engineer is charged with the responsibility of selecting and specifying the type of expansion joint he feels will perform best at the most economical cost to the owner. The first and perhaps the most difficult task is the selection of the proper expansion joint, after which the engineer must provide specifications and contract drawings delineating requirements for their manufacture or fabrication and for their installation during construction.

These contract documents must be explicit enough to fully describe what the engineer expects both in terms of materials and performance, without unduly limiting the bidders to either a single source (in the case of a proprietary-type expansion joint) or restricting them to details that may prohibit new improvements in design or materials that may have been made but not incorporated in the contract before the bidding and awarding phases.

There exist many documented cases where improvements that were made in the design concepts or materials of a specified expansion joint were prohibited from being incorporated into an ongoing project because they were made too late for inclusion in the bidding documents, and inadequate contract provisions did not permit their later acceptance or approval for use.

To be sure, changes should always be submitted for approval to the proper authority, so that they can be scrutinized and evaluated with respect to contract plans and specifications. However, even this apparently simple procedure often becomes an impossible task because allowances in the bidding documents prohibit changes, alterations, or substitutes, even when constituting a benefit to the owner.

The reason given for this approach is usually the legality of making changes after the bids are accepted and the contract has progressed. However, it need not be a hindrance if the specification is properly written and the engineering plans are correctly detailed.

One of the most beleaguering tasks the design engineer has to undertake is the selection of equipment or preassembled goods that are of a proprietary nature. This is especially so with expansion joints, because there are clearly many types of joints that are dissimilar in materials and configuration, but will, according to their manufacturers' literature and by appearance, produce the same end result. Expansion joints also invariably cover a wide range of prices, which is often the major criterion used for their ultimate selection; this may result in the cheapest first cost, but not necessarily the most economical life-cycle cost for that particular chosen application.

After selecting the type of expansion joint most appropriate to the physical and environmental conditions for a particular bridge, there is certain information the design engineer must include in the bidding documents, so that he obtains both the highest quality and most economical joint for the project.

BIDDING DOCUMENTS

Once the type and size of expansion joint are selected by the design engineer, the next immediate question is, How does one specify the expansion joint system so that the specifying agency and/or owner obtains the quality desired and remain within budget limitations.

Some engineers simply choose the easy way out by using an entire proprietary specification and adding the words "or approved equal." Proprietary specification refers to describing, in worded detail, patented features, the context of which constantly refers to or mentions a brand name. This procedure, without question, is the least professional and the one that most often will cause problems with contractors and other manufacturers not specifically listed.

The design engineer who adopts a proprietary specification, without deliberately intending to, will most likely

1. Create a specification that is too restrictive by specifying patented components or features of the proprietary product;
2. Eliminate competitive bidding, thereby substantially increasing construction costs;

3. Prohibit the use of improvements made in the product selected after the specification has been made part of the contract because of references to specific features or catalog information; and

4. Require additional cost factors to be used by the contractor when bidding to account for unknown elements and uncertainties with respect to alternates.

The discussion here is centered on the two following points:

1. What the design engineer must include or delete from the contract documents to obtain the highest quality expansion joint at the most economical life-cycle costs level, and

2. What the bidders or producers of expansion joints need to know so that they can furnish the proper joint at the lowest cost to the user or owner.

It is current knowledge among engineers that a poor specification can cause manufacturers or contractors, who have high quality goods or services to offer, to overbid. In other words, the contractor who knows how a product or service is to be tendered will account for those elements that would produce the quality he knows is expected, while the uninformed one will not.

Because every type of expansion joint has both attributes and shortcomings, it is wise to include some form of performance requirement in the bid documents.

To formulate a good specification, the engineer must first select the type of joint he desires and decide which joints he will permit as alternatives. To allow any type of joint during the bidding process would be a mere sentimental gesture and accomplish nothing in the way of quality. There could be cases where cost may be the primary objective in lieu of all other considerations, but it is generally not an acceptable criterion.

In order to base the specification on known acceptable parameters, it would be wise to develop a general classification system for expansion joints. This will enable the specifier to confine or simplify the wording and any other special conditions required that would normally be repeatable for use on future projects.

One type of joint classification for purposes of establishing bidding documents might be as follows:

I. Open joints (with or without drainage appurtenances)
II. Compression seals (unarmored or armored)
III. Strip Seals
  A. Elastomeric retainers or headers
  B. Steel retainers or headers
IV. Elastomeric joints (tension-compression type)
V. Modular and multiseal units
VI. Finger or tooth joints
VII. Aluminum (should be used as special classification)
VIII. Others (can have as many classes as there may be types)

Open joints fall into the category of gaps or openings in the concrete or steel deck with or without armor protection. Today engineers use troughs, gutters, and so forth beneath the gap to collect runoff water, thus protecting the bearings and structural elements below the deck surface. Open joints have all but been abandoned as a viable system. The spaces and troughs fill with debris and silt, eventually causing failure of the system or high life-cycle costs because of periodic maintenance demands.

Compression seals can be used with steel (armor) joint edges or with sawed concrete joint faces. Compression seals are made by several manufacturers, and there is considerable technical data published on the subject. Material characteristics and quality for the seals have been standardized, and the current ASTM specification appears to adequately cover these parameters. The use of general construction procedures and installation techniques along with these physical and material specifications will adequately ensure satisfactory performance.

Strip seals, on the other hand, are generally comprised of two basic components--the strip seal gland and the device that contains or secures the gland to produce a watertight seal. Therefore, although the gland is elastomeric in nature, the retaining device, whether mechanically locked, bolted in place, or molded as an integral part of the gland, can be elastomeric, aluminum, or steel.

Examples of the various types of strip seal systems, as currently produced, are

1. Elastomeric: Fel-Span, Elasto Dam, Trojan;
2. Aluminum: Alu-Strip, On-Flex, Delastiflex, and Acme Titan; and
3. Steel: Pro-Span, Maurer, Acme Strip Seal, and Gen-Strip CD.

The use of proprietary names, in giving these illustrations, is for clarity only, and is not intended to either promote or slight any manufacturer.

Category IV (in the outline given previously) would include the proprietary elastomeric molded type of joints similar in construction and configuration to Transflex and Waboflex.

Modular and multiseal expansion joint systems are more complex because they normally entail some form of expertise and use various engineered mechanical features to provide the movement range desired. The only caution to be given is that similar systems be specified for a particular project, without opening the specification to such broad implications as to allow steel versus aluminum or box-shaped lock-in seals versus strip seals to compete with one another.

Because of the nature of aluminum compared with steel and the differences in the ambient environment throughout the North American continent, this category, whether used with strip seal or any other type of joint system, should be considered as a special item unto itself when specifying. It is strongly suggested that when specifying aluminum, the designer give due consideration to all ramifications. For example, some concerns that must be evaluated and considered in design include fatigue life, brittleness in cold climates, bimetal or galvanic corrosion possibilities, coefficient of expansion in relation to the substrate or embedment materials, impact attenuation with reference to its weight versus load distribution, special handling and welding equipment required for original manufacturing and particularly for future maintenance work, salt corrosion of the aluminum, as well as oxides that may react unfavorably with embedment concrete.

After the basic type of expansion joint has been determined and evaluated, the specification can be written. For example, if an elastomeric joint (type IV) is selected, the bidding documents would describe and limit the contract to molded elastomeric joints with similar properties; if an aluminum (type VII) constructed joint is desired, those manufacturers that have acceptable aluminum joints would be competing; similarly, if it is desired to incorporate into the contract a high-quality expansion joint such as the Maurer or Acme MSB series, with

heavy-duty, high-strength components, the design engineer should specify that type of joint and include within the specifications those features or approved alternatives that will be permitted.

This is an important point because when specifying two or more completely different types of expansion joint systems for use on the same project, the least expensive type will undoubtedly be bid lowest. If this is the intent of the design engineer, then why specify more than one type?

Also, another problem is created because two specifications must be written for the same item of work because a single specification describing two different systems would be confusing and inadequate.

Finally, a well-written specification allows for one or more approved equivalents (no two similar joints are absolutely equal), and will thereby create competitive bidding, thus obtaining the best economical joint.

The specification should include, but not be limited to, the following items:

1. Description: General description of the type of expansion joint desired, allowing for approved equivalents.
2. Materials and performance: This section should contain material requirements spelling out testing procedures and sampling techniques or methods.
3. Construction: Construction requirements and installation procedures should be detailed only to the point that the supplier and contractor know what is expected. This section should also include shop drawing requirements, site preparation, and special conditions not otherwise anticipated in the course of installation.
4. Method of measurement: Method of measurement should clearly delineate the limits and how measurements are to be taken so that there is no question as to the quantity to be paid for.
5. Basis of payment: The last section merely contains the elements for consideration in payment.

The foregoing general list is a suggested guide. There are many formats to writing specifications, and there is absolutely nothing wrong in adopting any style as long as it is clear as to exactly what is intended.

More specifically, some of the items to be considered in writing a specification are as follows. The general description should denote the type of expansion joint desired and indicate to some degree the basic quality required. It is also important, when bidding, to know sizes and quantities of material samples required for testing purposes, including the time that the samples should or will be taken. If samples are not required, the certifications desired by the owner should be spelled out.

Additional uncertainty is created when the material specification describes one material, when actually another is to be furnished. For example, if a preformed elastomeric compression seal is fully described, and a lock-in type seal is mandated, the material specification will most likely not be applicable to a large degree. Both seals are made from similar materials, but they operate under dissimilar engineering concepts. Therefore, if the specification is applied with indifference, the lock-type seal will normally fail the recovery tests (physical characteristic), ensuring difficulties between the supplier and materials testing agency. The specifying authority must be flexible enough to recognize real differences in products, especially those material attributes that relate to performance criteria, and not create additional "red tape" and undue delay when evaluating an equivalent item.

On the other hand, material specifications must be explicit to the point of including alternatives and equivalents either by describing them or by reference, so that material testing agencies will be aware of differences, and approved procedures will remain simple and unencumbered by bureaucratic nitpicking.

Painting and coating requirements should be outlined in this section of the specifications. Whether using a primer, rich zinc paint, special epoxy paint, metalizing, or hot dip galvanizing, parameters such as thickness, areas to be coated, and restrictions in their use should all be described. Often the painting specification for structural steel is used. This should be avoided, if possible, because expansion joints are fabricated (manufactured) products; therefore procedures, as outlined for large monolithic units, cannot always be followed. This is especially true when manufacturing the more intricate and complicated multisealed or modular-type joints. For instance, because of the time it takes to fabricate and assemble component parts to make a composite unit, it is not always possible to paint the joint within a few hours of the grit-blasting operation.

Another point of concern is to make allowances for repairing galvanizing, paint, or other coatings when the assembly must be made in short lengths that can be safely and adequately handled and then spliced together for final assembly.

After specifying general material requirements, a short section on service expectations and performance would be applicable. Physical parameters could also be interjected at this point.

In the case of waterproof or sealed expansion joints, a field test consisting of flooding the joint and observing it over a brief period of time (1 hr) would be beneficial to determine if the initial installation is satisfactory.

Only prolonged field use should be considered a barometer by which performance and life expectancy may be judged. No amount of laboratory testing can guarantee that an expansion joint system will perform to expectations. There are too many interacting variables, which are independent of the quality of the system, that could affect the field performance of the system.

The known physical characteristics of materials, including their life expectancy under given conditions of stress, should enable the specifying engineer to evaluate any system proposed without requiring exotic, redundant, or unwarranted long-period testing procedures.

Known physical characteristics are understood to be those properties that have been adopted and accepted by current industrial standards, such as:

1. Specifying A36, A588, or grade 50 steel immediately connotes its yield point, tensile strength, chemical analysis, unit weight, and other well-defined parameters; and
2. Specifying neoprene rubber by suitable ASTM designation would immediately account for material indices such as tensile strength, elongation, durometer, and compression set.

Societies such as ASTM, American Concrete Institute, American Steel Construction Institute, and the like spend many years developing material specifications that can be easily (if need be) modified or tailored to one's needs.

Major points to cover under the construction section are items directed to either or both the contractor and manufacturer, such as special handling, unique field operations or techniques required for

proper installation, and subsequent satisfactory performance.

This would involve other items of work such as tolerance for setting grades and acceptable deviations in placing sealers or other appurtenant components needed for installation.

Certainly structural steel tolerances should be accepted as standard, because in the manufacture of armored expansion joints, machining is not one of the operations, and the state in which steel is received by the manufacturer will affect the final overall dimensions and straightness of the joint. Small deviations in measurements and physical characteristics that do not affect the performance of either the sealer or joint system should also be permitted.

Regarding method of measurement, in most cases there is a definite advantage to using payment by lineal feet supplied versus a lump-sum arrangement. Most bidders can and often do give their lowest unit price if they can be certain that any changes in quantities furnished, as ultimately needed on the job site, will be paid for.

Although a specification may be well written, certain other data and information are needed to achieve the desired end results. These data are normally described in the engineering contract plans.

The well-known cliché, "a picture is worth a thousand words," is especially relevant to the subject under discussion. Intentions, ideas, and desires of the design engineer can be graphically incorporated in the contract plans, with sufficient notes to ensure the meaning of the specifications.

The contract plans should clearly indicate physical characteristics such as (a) anchorage system desired or minimums required; (b) typical sections of the joint, including slider plate assemblies and general treatment at pedestrian walk areas, without detailing every dimension to the nth degree; (c) blockout geometry, when used; (d) details and geometry of supporting structural members, where applicable; and (e) specific notes dealing with the joint system's manufacture or fabrication and installation or erection procedures, especially when relating to other required standards or codes.

The kind of information to be contained in the general notes on drawings, other than special installation instructions or restrictions, would be related to painting or galvanizing, field splicing of seals or metal members, class of steel or other metals, welding code requirements, material requirements for specific components not indicated elsewhere, and other sundry items to either emphasize or clarify the intent of the drawings and specifications.

There are two items most often omitted from the contract plans, but nonetheless important, that would be significantly beneficial to manufacturers and suppliers: the ambient temperature range and the anticipated or design joint movement. These data are necessary when bidding projects because products of manufacturers differ slightly in movement ratings, and a determination of which alternates would be acceptable may have to be made.

Certain details must be clearly dimensioned and delineated, such as the size and spacing of rebars, studs, gusset plates, or other relevant anchorage systems, as well as plate sizes for slider assemblies. These are items normally designed by the engineer and are generally independent of the type or make of expansion joint used.

Proprietary cross sections may be used to depict type and materials desired by the engineer for obtaining an end result; however, notes allowing for minor deviations in dimensions and in design configuration to other equivalents can and should be used so as to allow both the specifying agency, the contractor, and the manufacturer latitude so they can adapt the expansion joint that is ultimately selected and approved to the specific structure.

The use of overall dimensions, as applied to the expansion joint system, is considered necessary in order to furnish proper details for fabrication drawings. However, once again, the engineer is cautioned not to overdo the dimensioning when using a proprietary design. The product specified will, undoubtedly, conform to all the general dimensions, but any equivalent product will have minor variations in dimensions, which in most cases will not affect the true intent of the design.

Therefore, it is maintained that, for practical purposes, it is not necessary to show every detail of an expansion joint if it is proprietary, because extraneous information may tend to confuse the actual purpose of why it was shown in the first place.

It is necessary, however, to detail and annotate any item added to a proprietary joint system that would be expected to be furnished, regardless of who the ultimate supplier may be. This would include attachment brackets, structural shapes made a part of the system, and the like.

On the other hand, designs of nonproprietary expansion joints for manufacture or fabrication and installation by the general contractor must contain all necessary detail dimensions. In this case, the engineer is conveying information to the uninformed or nonspecialist. This same reasoning should equally be applied to those portions of proprietary expansion joints that are actually nonproprietary, such as rolled steel sections added for anchorages or slider plate assemblies and so forth. The bidder needs to know the sections required, the type and grade of steel, the thicknesses where appropriate, and basic design details of the unit or assembly.

The only method the engineer has of assuring a clear understanding of his contract documents is either the use of an example (naming a proprietary product) to denote quality or, in the instance of general drawings, showing enough detail for its manufacture or fabrication. For example, all weld sizes and lengths, specific material requirements, as well as exact sizes of all parts must be shown on nonproprietary components or expansion joints; and typical sections of proprietary expansion joints should be used where they will convey the engineering parameters desired. This will enable all bidders to evaluate the contract documents in a similar manner and conform to the same standard.

SUMMARY AND CONCLUSIONS

There is, perhaps, much more work needed in writing adequate and competitive specifications for expansion joint systems. The purpose of this paper is to bring to the design engineer's attention some of those aspects of contract documents that, if not properly handled, would either result in controversy or additional costs to the user.

When specification or drawings are not clearly understood, problems will arise that both engineers and suppliers do not want. The supplier wants to be able to bid his product and should be given the opportunity to do so, whenever possible, within the limitations of that product. The design engineer wants and should receive the quality he desires for the most economical costs obtainable.

In conclusion, specifying agencies should write specifications that clearly describe the desired expansion joint and should draft contract drawings that indicate graphically the inherent characteris-

tics and physical requirements of the joint. The drawing should also show how the joint is to be placed, connected, and installed. In this way the specifying agency will relieve itself of much controversy, and at the same time they will obtain the right expansion joint at the right price through competitive bidding.

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Vertical Movement of Jointed Concrete Pavements

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ABSTRACT

The vertical deflection of a concrete pavement under truck loading may be the determining factor in predicting the service life of the pavement. Consequently, it is of prime importance to know the effect of different variables on this vertical movement. To study experimentally the effects of the variables, a test pavement was constructed as part of US-23 in Chillicothe, Ohio. Data have been collected on this pavement continuously since 1972. To isolate the variables, the pavement was divided into 10 sections of approximately 10 joints each. Vertical measurements were taken by using a truck with a measured axle load. The measurements provided continuous plots of the vertical movements as the test truck traveled over the joint. Measurements were repeated at different speeds to determine the effect of truck speed on pavement deflection. Measurements were also repeated both morning and afternoon to study the effect of pavement curl. The measurements were analyzed statistically to determine the relative effects of the different variables on the behavior of the slab. The analysis indicated that there is a significant effect on slab behavior caused by difference in the subbase, location of the truck on the pavement, speed of the truck, and time of measurement (morning versus afternoon). Only a minor effect was noted due to spacing of joints, types of dowels, and a configuration of the saw cut.

The vertical movement of pavements is affected by wheel loadings and expansion and contraction caused by temperature and moisture changes. Portland cement concrete pavements are usually jointed to accommodate this movement. The results of uncontrolled pavement movement may be cracked slabs, pavement blow-ups, and bridges tilted or pushed out of skew.

Horizontal movements are usually assumed to be a sinusoidal variation of expansion and contraction, thus causing the joint to open and close. Of course, many other factors affect this movement. The vertical movement depends on both traffic loads and the curl of the pavement caused by temperature change.

STUDY OBJECTIVE

The objective of this research was to determine the actual magnitude of the vertical movements of the pavement. Because there are several factors that may affect movement, each factor was considered as a variable. The variables were then isolated to determine the effects of each. At the risk of "reinventing the wheel," even those assumptions that are commonly accepted as fact were challenged. The factors considered to be of prime importance were type of subbase, coating of dowel bars, joint spacing, configuration of the saw cut, and use of skewed joints. Combinations of these variables were incorporated into a test pavement, and were studied for a period of 8 years by actually measuring pavement movement (1-3).

TESTING PROGRAM

The test pavement is a section of the southbound lane of US-23 approximately 0.6 mile (1 km) long. The pavement is a tangent section on an easy grade. Truck loads are heavy, but the average daily truck traffic is not high.

The test section is reinforced concrete, 24 ft (7.3 m) wide and 9 in. (229 mm) thick. Most of the pavement is laid over a granular subbase, except for a 776-ft (237-m) section, which is laid over an asphalt-treated base. Spacing of the joints was set at 17, 21, and 40 ft (5.18, 6.4, and 12.2 m). The dowels used were standard steel dowels and plastic-coated dowels. The configuration of the joints also varied. There were 0.5-in. (12.7-mm) joints, 0.25-in. (6.4-mm) joints, and one set of joints with a beveled saw cut. Data about each of the variables are given in Table 1.

Instrumentation

Vertical movements were measured with a linear motion transducer and a strip-chart recorder. The