VALUE ENGINEERING STUDY

ON

Methods of Controlling and Sealing Contraction
Cracks in Concrete Canal Lining

by

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# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>1</td>
</tr>
<tr>
<td>Conclusions</td>
<td>5</td>
</tr>
<tr>
<td>Principal Conclusion and Recommendation</td>
<td>5</td>
</tr>
<tr>
<td>Secondary Conclusions</td>
<td>5</td>
</tr>
<tr>
<td>Introduction</td>
<td>9</td>
</tr>
<tr>
<td>Causes of Cracks</td>
<td>11</td>
</tr>
<tr>
<td>Development of Contraction Joint Sealing Practices</td>
<td>14</td>
</tr>
<tr>
<td>Random Crack Sealing</td>
<td>20</td>
</tr>
<tr>
<td>Jetting and Grouting Behind Concrete Lining</td>
<td>23</td>
</tr>
<tr>
<td>Reduction of Seepage Through Subgrade Preparation</td>
<td>24</td>
</tr>
<tr>
<td>Guest Speakers</td>
<td>25</td>
</tr>
<tr>
<td>Selected References (Annotated)</td>
<td>26</td>
</tr>
<tr>
<td>Appendix</td>
<td>29</td>
</tr>
<tr>
<td>Minutes of V. E. Team Meetings</td>
<td></td>
</tr>
</tbody>
</table>
Between October 19, 1966 and May 1, 1967, Value Engineering Team No. 11 held 22 meetings devoted to the "Study on Methods of Controlling and Sealing Contraction Cracks in Concrete Canal Lining." At 12 of these meetings guest speakers were heard who discussed the many aspects of crack formation, filling, and sealing. Each speaker was an expert in his field and was actively engaged with the problem in some phase of research, design, construction, or operation and maintenance. Each speaker discussed the overall problem as he saw it, as well as his particular specialty. As a result, certain areas were overlapped by two or more speakers, giving the team an insight into the many interpretations of the same problem and its various solutions.

The various parts of the problem covered by the speakers included design of concrete linings and joints; construction of linings and joints and installation of joint sealers; seal placement methods; durability; effectiveness; cost of sealants; design and fabrication of preformed joints; relative values of alternative types of linings, membranes, or waterproofing methods; canal maintenance problems including crack and joint resealing; discussions of joint spacing; causes of lining cracks, discussion of various commercial sealing compounds; history of joint forming and filling; need and advisability of providing joints from concrete technologists viewpoint; effect of high hydraulic head on sealants; differing needs for small and large canal cross sections and low and high heads; thin and thick linings; hot and cold climates; always wet and alternately wet and dry canals, and many other items of concern.

It became apparent to the team, after hearing a few of the experts, that various organizational units in the Bureau had different ideas about what should be done and what results were desired. The various parts of the joint sealing development program are well scattered throughout various divisions in the Bureau and each division conducts its investigation as it sees fit—not necessarily coordinated with the work in other divisions. Design, Construction, Irrigation Operations, and Research are all engaged in one or more phases of the work as are some of the regions. Also, each division or region has two or more organizational units involved in one or more phases of the program. Yet, it could not be determined by the team that any division, branch, office, or segment felt responsible for the entire program, for the actions taken, or for the evaluation of the results obtained.

Because of the many unresolved facets of the problem, and because none of the joint filling materials, methods of application, joint designs, or other factors have been used consistently or with any real degree of satisfaction, the team has unanimously decided that a value engineering study, in the usual sense of the word, cannot be made at this time. However, the team has come to certain conclusions based on an analysis of the problem and solution in its present state of development. These conclusions, it is hoped, will help point the way toward proper administrative measures which could simplify and hasten the solution of the problem as it presently exists.
It is the judgment of the team that although the joint problem is continually being investigated and many "Standard" procedures have been developed and adjusted, ideal practices are still in an experimental stage—both as to the choice of materials and the methods of application. Many more experiments and evaluations must be made before final decisions or recommendations can be made. Also, there must be some unanimity of purpose and some standard of achievement established before proceeding with the development of joints and sealers. For example, it is not an universally accepted fact throughout the Bureau that watertight linings are practical and desirable. Design believes in, and strives for, a "bottletight" lining. Construction does not believe this is economically possible. In Irrigation Operations it is not clear why we seal joints because some canals have been turned over to them with preformed but unsealed grooves. Field groups (districts) buy sealing materials and experiment with installation methods on the advice of salesmen, without regard for the Denver Office research program, which they may not know exists. In an attempt to gain some unanimity of action, the designers may then specify the use of these materials, in the hope that the field people know something we do not. At times, therefore, undue emphasis has been placed on worthless materials and methods. This situation then leads to the principal conclusion of the team, i.e.: "That an orderly solution to this problem can only be attained by conducting the necessary investigations—research, design, construction, inspection, testing, and evaluation of criteria for specifications preparation—under the guidance of a single administrative unit."

The unit, which might be a person, section, branch, or a combination of personnel from these, would be responsible for all phases of crack and joint filling and would coordinate all Denver Office and regional work in this field. Their work would be planned to investigate the differences in procedures, materials, or specifications caused by climate, joint exposure, canal size, value of lost water, thin, thick, new or old linings, contraction joint versus random crack, impervious membranes beneath the lining, and many other factors. The new unit would also assign parts of the investigation to various divisions and/or regions in the Bureau where experience has shown that the work belongs and can best be done. For example, investigations of materials characteristics are best carried out in Research, whereas installation procedures and equipment development tests are best done in Construction. Resealing and maintenance research would best be conducted in Irrigation Operations; and actual full scale testing in the regions.

Funds are needed to conduct certain investigations which experience has shown to be necessary. For example, a stated policy for underwriting some of the contractor's experiments in groove forming and getting seal placement systems into production and operating as part of the lining construction train should be established. Payment to the contractor for some of the experimental procedures now necessary at the start of each job would improve cooperation and accelerate development of the finally adopted sealing equipment and methods. Funds for the development of alternate methods and materials would also be helpful in providing a competitive atmosphere for finding the best answer in the least time.
The conclusions herein drawn and discussed are not claimed to be original with the team; rather, they have been gleaned and assembled from remarks made by one or more, and sometimes a majority, of the speakers who talked to the team. It was almost a unanimous thought, for example, that an intensive and coordinated research program should have been started 2 years before trying to solve the joint problem on the San Luis Canal. Some 160,000 feet of Constop had been placed in this canal before it was realized that the strip was too deep in the concrete and that the planned cracking was occurring in the wrong places. Other thousands of feet were placed before the transverse and longitudinal joint crossings were recognized as a possible source of leakage. Many other thousands of feet of joint were placed not knowing the best answer to many other problems.

Is Constop better than the Dill Strip, or vice versa? Or does the Bureau-developed strip show more promise than either of these? Is the presently used joint spacing too close or too wide? Will vertical motion of the slabs break the seal joints? Does subgrade type affect groove spacing requirements and the amount of random cracking? These and many other questions require answers which can only be derived from planned and controlled investigations. A great deal has been learned about groove (or joint) and crack filling in the 20 years this activity has been in progress. Much of the information is negative in nature in that it outlaws materials, practices, and theories that are not acceptable, but very little specific information has been recorded for all to read and therefrom benefit. Rapid advancement in the last few years in creating better sealing materials and applicators makes it imperative that an accelerated development program be initiated to keep pace with the vendors and their claims. Some of the proprietary products now being offered to the Bureau for immediate use do seem to be superior to some of the generally available compounds used in the past. Vendors have invested heavily, in some cases, in sealer installation equipment and are making claims that they have the answer to our problems. The consensus of Bureau engineers seems to be that some of these products do have considerable merit, but feel that the claims of the vendors are overstated. For example, "Constop" seemed to provide the answer to our sealing problem in a large canal. A few tests have indicated, however, that the longitudinal and transverse groove crossings have produced cracking at these points that may have allowed water leakage around the Constop and into the subgrade. It is still being debated whether the quantity of water lost is significant or harmful. Nevertheless, some Bureau engineers feel that to solve or circumvent the problem, Constop might more properly be used in the longitudinal joints and a polysulfide-type sealer in the transverse grooves. Competitors of "Constop" such as "Dill Strip" and others, and some Bureau engineers, feel that the "Constop" principle is good but that a better plastic strip (improved in cross sectional configuration) would solve the problem. Bureau engineers have developed a plastic seal strip having apparently better characteristics than the available strips. Patent rights as they affect several brands of strips may enter the picture before the issue can be settled.
Most recently, however, a new sealing concept, product, and applicator have been used in a limited number of test grooves, both by the Bureau and the State of California. This is a two-component polysulfide sealer mixed in the applicator gun head and applied into a groove formed moments before in wet unset concrete. The polysulfide hardens within seconds, then bonds to the wet concrete as it sets and dries, using the reaction of the setting process to create the claimed good bond with the cured and dry concrete. This Thiokol Company product seems to have great merit since the entire operation of forming the groove, filling the groove, and refinishing the roughened concrete surface adjacent to the groove after placement of the sealer can all be done with equipment attached to the construction train. Costs are said to be about half as high as some other methods which have been used. At present, only transverse grooves have been sealed with this new material; Constop has been used in the longitudinal joints. The consensus is that the Thiokol gun-mixed-and-applied product is good and shows promise of being universally and economically useful. Recent tests on the San Luis Canal, however, showed some bubbles in the material as it was placed in the joints.
CONCLUSIONS

The principal conclusion drawn by the team after an extensive investigation has been given and discussed in the Summary. It is repeated here:

Principal Conclusion and Recommendation

The methods of controlling and sealing contraction cracks in concrete canal linings are still in the experimental stage and neither methods nor materials have yet been standardized. Also, no standard specifications or instructions describing the required operations have been adopted. Consequently, a conventional value engineering study could not be made. Before this can be attempted many more experiments must be made and evaluated, and the necessary standards adopted.

An orderly solution to the problem, resulting in these standards, can only be attained by conducting the necessary investigations—research, design, construction, inspection, testing, evaluation of criteria for specifications preparation, and dissemination of information—under the guidance of a single administrative unit.

This unit should include representatives from Research, Design, Construction, and O&M, and should be provided with project and research funds and authority to plan, execute, and enforce a logical development program to produce usable results as currently required. To expedite the obtaining of usable results, all of the specialized services available in industry and in the Chief Engineer's and regional offices should be utilized. This principal conclusion was reached after considering the many facets of the problem as given in the "Secondary Conclusions."

Secondary Conclusions

1. Under usual field conditions there is no sure economical and practical way of preventing the cracking of concrete canal lining. The amount of cracking is influenced by many factors, some amenable and some not amenable to control, including (a) water and cement content, (b) type and potential degree of chemical reactivity of the aggregate and cement, (c) placing temperature of concrete, (d) curing or lack of curing, and (e) ambient temperature variations. The first four factors, under the present state of the art, are amenable to nearly complete control and result in minimal cracking. There are no practical means of controlling factor (e) which is responsible for most significant cracking, including those cracks which form in grooves provided for this purpose. Some efficient means for controlling cracking (producing cracks where desired), including research into nonshrinking cement, is needed and some method must be developed for filling the cracks when embedded seal strips (waterstops) are not used. At present there is no single sealing material, or joint preparation process, or spacing and arrangement of contraction joints, or any other known uniform treatment that can be applied
successfully to all concrete canal linings. Materials and/or processes required for large canals with thick linings will necessarily be different from those used in small canals having relatively thin linings. Heat versus cold, wetting and drying versus continually wet, new construction versus maintenance on old construction, and other factors will also affect the choice of procedures to be followed.

The suggested development program should include the preparation of specifications to cover the many variables encountered in a contraction crack sealing program.

2. Joint preparation and/or the sealing process should be made a part of the lining operation, as much as possible, and equipment should be developed to automate the process to the most practical degree. Elimination of hand installation work and associated operations such as hand finishing behind a waterstop laying machine will reduce the sealing costs appreciably. At times, up to 20 concrete finishers are used to obtain the grooved and finished concrete in a large canal. Placing all operations in an automated train and accomplishing all work in a single pass of the equipment would reduce costs to a minimum.

3. Development and improvement of molded plastic waterstops such as Constop, Dill Strip, USBR Strip, etc., should be pursued since they show promise. Exact cross-sectional dimensions of the strips for a range of slab thickness should be established. An accordion-fold type of stop might be useful if the contraction joints are expected to move more than about 1/8 inch. The fold in this type waterstop prevents tension in the plastic material when the slabs move. The hollow bulb feature found in most of the plastic waterstop shapes is expected to be of value when differential movement of the concrete slabs places the plastic material in compression.

4. Whenever possible, the Bureau should provide assistance to the contractor, equipment developer, or materials manufacturer to investigate new groove, sealants, and installation procedures. This assistance could be in the form of payment for trials of newly developed equipment and materials and/or in the form of technical assistance in the laboratory or field.

5. Development of sealants should be guided by the desire for long life and low cost. Ideally, waterstop or sealing material should have a minimum life of 50 years and an installed cost of about $0.25 per lineal foot. Both industry and the Bureau believe this cost is currently obtainable. Costs of sealant materials are not yet stabilized to the point where they are reflected in uniform bid prices. Present bidding practice seems to be to get as high a price as possible because of the many uncertainties facing the contractor.

6. In considering alternative methods and materials, modified polysulfide sealants seem to be most effective in resisting the wearing effects of high velocity water containing suspended silt or sediment. For these
under the same conditions, polyurethane, silicone, and ordinary polysulfide show more wear but are satisfactory; while glass reinforced asphalt mastic tape (Ram-Nek), rubberized mastic sealer, neoprene-hypalon sealer and USBR rubberized asphalt mastic are unsatisfactory. For lower water velocities and considerable exposure during the nonirrigation season, extended polysulfide and the Ram-Nek mastic tape show promise. Where exposure and weathering are minor factors, USBR rubberized asphalt mastic appears to be satisfactory. Ram-Nek has been found useful for filling random cracks, but more efficient installation methods should be investigated. General Electric Company has predicted it will develop a silicone sealant for use in underwater sealing, or for wet joints, within a year. Development of this sealant by General Electric Company should be followed.

7. The use of a soil-cement pad has been suggested for use under concrete linings built over rocky and permeable areas. The pad would eliminate piping of fine materials into the subgrade. The use of waterproof membranes, such as sprayed asphalt or butyl-rubber sheathing, beneath a concrete lining has also been suggested as a practical substitute for joint and crack sealers. Grouting behind older linings has eliminated seeps and waterlogged land adjacent to the canal. Controlled gravity pressures on the grouting system was used to prevent displacement of the lining.

8. Tests using polysulfide of the type meeting California Department of Water Resources specifications show satisfactory results in the sealing of narrow cracks. However, according to the Department of Highways, Ontario, Canada, polysulfides, polyurethanes, or hot-poured rubberized asphalts should not be expected to provide adequate sealing for more than 2 years in concrete pavements. This difference in outlook should be investigated.

9. In working with preformed grooves (to be filled later with sealant) flexible and reusable groove forms have been found superior to rigid forms or hand-formed grooves. Reusable forms seem to result in lower costs.

10. The two-component polysulfide sealer, developed by the Thiokol Corporation, which is mixed in the applicator gun head in a continuous process and which is applied in a groove formed only moments before in the wet unset concrete, seems to have real merit. Both the product and the application procedures should be further investigated and developed.

11. The depth to which grooves should be formed in the slab to insure a crack forming in the groove (one-third the thickness of the slab is now used) and the spacing between grooves (a maximum of 15 feet is now used) seem to be satisfactory, in general, but may need further investigation. Groove spacing in small canals (thin lining) may need to be reduced.

12. The possibility of developing sealing strips that would prevent leakage but would also act as a check valve to relieve unbalanced pressures
behind the lining should be considered. Similarly, flap valves (check valves) that would be used in conjunction with seal strips at joint intersections should be investigated.

13. As a basis for determining allowable costs for new developments, the present system of grooving and filling grooves is costing 3 to 4 percent of the total lining costs.
INTRODUCTION

Water in the 17 Western Reclamation states is in overall short supply and generally poorly distributed. Since the land was first broken by the plow, individual farmers at first, then groups of farmers, followed by state and Federal agencies have sought to remedy the deficiencies in distribution. Dams and distribution systems have been built using the least costly systems available at the time. They have increased in cost as larger rivers have been harnessed and more elaborate and complex distribution systems have been required. Initially, more than ample water was available for all anticipated uses and little effort was expended to reduce losses from seepage or evaporation. However, since the supply of unused or unappropriated water becomes increasingly scarce and expensive, conservation of water becomes more important and strenuous efforts are being made to minimize, if not totally prevent, losses from storage, evaporation and transportation. It is the latter of these with which V. E. Team No. 11 is concerned.

Small quantities of water have been transported without measurable losses through pipes, and larger quantities can be handled just as effectively. The costs for the larger conduits are sometimes high and difficult to justify, however. Often a more economical approach is through use of open canals. Such canals have been used for centuries with improvements in construction, from unlined to reinforced to nonreinforced concrete lining, being made. The more elaborate linings were adopted as the amount and value of the water transported increased. Concrete linings prior to 1947 were mainly of reinforced concrete design and were expensive, but did minimize cracking from heaving and subsiding of the subgrade. Unreinforced linings laid down by lining machines were subsequently introduced with a resulting relatively low cost, but were prone to random cracking from thermal and shrinkage stresses as well as those resulting from subsidence or heaving of the subgrade. Control of the potential thermal and shrinkage cracking was subsequently obtained by forming grooves in the fresh concrete. This method, to a greater or lesser degree, resulted in formation of cracks in predetermined locations which facilitated sealing by mechanical means. Random cracks are not amenable to such means and must be handled individually.

Since water losses through cracks, both random and in grooves, are considered to be excessive in some cases, the control of those losses presents a major problem in present day canal construction. During the past 4 years, and referencing construction on the San Luis Canal in particular, many different methods and materials have been used experimentally in an effort to establish the optimum combination for control of leakage. Methods for forming and subsequently filling grooved joints have been investigated, as have various materials, such as rubber, plastic, and bituminous compounds for sealing the random and purposefully formed cracks in grooved joints.

Other experiments have been conducted on types of bedding or backfill materials, plastic blankets, and subgrade preparation to minimize
formation of random cracks resulting from heave due to frost or expansive clays and from subsidence. More work needs to be performed on all phases of lining of canals. New products, especially one that will adhere to moist surfaces, must be developed and new techniques devised to effectively and economically seal canal linings.
CAUSES OF CRACKS

Concrete, between the placing phase and final use, is subjected to an autogeneous change and also to many forces, some autogeneous and some external, which may result in cracks in the hardened material. Upon mixing the constituent parts and placing the resulting mixture, but prior to final set, the concrete undergoes a densification in which the hydrating cement paste occupies less volume than the total volumes of the cement and water separately. This volume change is largely accommodated during the plastic state and is not detrimental. However, all stresses occurring after final set do, to a greater or lesser degree, affect the original structural integrity of the hardened concrete.

Taken in chronological order of their occurrence in concrete canal lining, stresses result from:

1. Temperature change during and subsequent to curing;
2. Moisture loss subsequent to curing;
3. Temperature change upon flooding and draining of the canal;
4. Chemical reactions;
5. Freezing-thawing exposure;
6. Too dry a subgrade;
7. Subsiding or heaving of subgrade; and
8. Back pressure in unwatered canal without appropriate drains.

Of these eight stress-producing factors, the first six are amenable to some degree of control, which might minimize cracking. The latter two factors are not so amenable but, if anticipated, could be largely nullified through preparation of subgrade or structural design.

The principal crack-producing factor, that of temperature change, is effective with the first temperature drop after placing, generally during the first night thereafter. Assuming a 30° F ambient temperature differential, a thermal coefficient of expansion of 5.5 millionths in./in./°F, and a modulus of elasticity of 1,500,000 psi, a stress of 247 psi would result. Concrete in general develops less than 5 percent or 15 psi of its average 28-day shear bond strength of 300 psi at 2 days' age. This cannot successfully resist the 247-psi tensile stress accompanying the assumed 30° F temperature differential, and cracks form usually at the point of least cross-section area. This development of cracks takes place regardless of the ambient conditions existing, the width of the crack depending largely on the differential between the maximum and minimum temperatures to which the concrete is subjected during the first day or two after placement.

With the cracks already formed by temperature differential previously described, the remaining factors which have autogeneous effects usually tend to widen or constrict the cracks. Drying shrinkage in the laboratory, where it develops under the controlled ambient condition of 50 percent relative humidity, generally varies between 350 and 850 millionths at 28 days depending largely (other factors being equal) on the mineralogic composition of the aggregate used. Approximately 40 percent of
these shrinkage values or 140 to 340 millionths would be expected of similar concrete in the field. A situation where drying shrinkage could produce intermediate cracks exists where the subgrade is rough enough to resist sliding. Using concrete having a modulus of elasticity equal to 2,500,000 psi, a potential length change of 28 millionths, 20 percent of the minimum value above estimated for 14 days' age, a stress of 70 psi is developed. This figure exceeds the estimated 60-psi shear bond strength developed at the same age. If sufficiently restrained by the rough subgrade intermediate tension cracks could form.

Upon watering and unwatering the canal, only a change in magnitude of existing cracks would be expected, the direction and magnitude of change being controlled by the net length change resulting from temperature and absorption. In these operations, the introduction of relatively cold water would cause the contraction in the concrete due to temperature drop, and simultaneously an expansion from absorption of water. This expansion would be approximately 50 percent of the initial contraction resulting from drying shrinkage.

Cracks may be caused by chemical reactions in the hardened concrete. These are caused by (1) the alkalies in cement reacting chemically with the reactive rock types, such as chert, volcanic materials, opal, etc., occurring in the aggregate, and (2) the reaction between the soluble sulfates in the ground or groundwater and the aluminates, principally tricalcium aluminate, (C₃A), occurring in the cement. The first reaction manifests itself in a small-dimensioned map or pattern cracking, which cracks are subsequently enlarged by weathering. These cracks are not amenable, because of their great number and random distribution, to sealing; but the condition which causes them can be eliminated through use of cement low in alkalies, 0.60 percent sodium equivalent or less, and in extreme cases by the simultaneous use of an effective pozzolan. The second reaction, which has similar effects, can be controlled through use of sulfate-resisting cements, Types II and V, which have restrictions of 8.0 and 5.0 percent, respectively, placed on C₃A content. An increase in cement content of the concrete mixture provides a further increase in protection. Sealing of cracks resulting from this reaction also is not feasible.

Weathering of concrete in the form of freezing-thawing is another source of cracks and general deterioration, usually located in a strip at the water surface. This is caused by freezing of (1) the absorbed water, and (2) free water, generally defined as that water in excess of the amount required for cement hydration which upon freezing, undergoes a 9-percent increase in volume with resulting cracking and spalling. These cracks would have to be individually treated because of their size and random distribution. However, they should not pose a problem because, with the use of air entrainment specified for all Bureau concretes, the deteriorating effects of freezing-thawing are greatly minimized if not entirely eliminated.

Cracks in concrete slabs caused by subsidence produced by consolidation or piping, or heave of the subgrade cannot always be predicted with
certainty. In areas of subsidence or expansive clays, the slabs could be reinforced to accommodate the anticipated condition and thus minimize the potential cracking. However, those cracks that do form are random in distribution and in sealing must be handled individually.
Prior to 1947 concrete canal linings were reinforced with steel reinforcing bars. At this time the principal reasons for lining were to reduce the size of the canal section by providing better flow characteristics, to help reduce seepage, to promote canal safety, to improve the canal appearance, and reduce maintenance. Cracks did occur at the construction joints but random cracking was at a minimum, largely controlled by the reinforcing steel. The overall watertightness of the section was far superior to that of the unlined canal. However, this method of canal construction proved to be very expensive.

Since 1947, steps have been taken to produce lower cost canal lining by the use of unreinforced concrete laid down by slip-form and mechanical pavers. One of the first unreinforced concrete linings produced by the Bureau of Reclamation was on the Friant-Kern Canal. The first lined sections, about one-fourth mile in all, were installed without grooves. With no inducement for cracks to form in predetermined locations, there was excessive and extensive random cracking. Also, a short, experimental section of paving, with and without grooves, was placed over an asphalt membrane laid on the earth. Difficulties in placing the concrete without rupturing the membrane were experienced.

The first grooves were installed under a change order by cutting the hardened concrete with a diamond saw; therefore, they were very expensive. The contractor tried to saw grooves in green concrete but aggregate was pulled loose. Later, when the aggregate was firmly embedded, random cracking was found to have already occurred; therefore, sawing was discontinued. In succeeding reaches, grooves were formed by hand methods during the concrete placement, but the grooves located on the side slopes tended to close due to the downslope movement of the unset concrete.

Different methods, including the use of a stiffer concrete mix, were developed later and produced good grooves. These grooves were subsequently filled with sealants in order to increase watertightness of the canals. The sealants were mixtures of asphalt or mastic with a solvent to increase workability. These were hand placed and tended to run out of the groove and only partially adhere despite careful control procedures.

The difficulty and high cost of forming the groove subsequently led to the development of molded plastic strips, cross shaped in cross section, installed in the fresh concrete during placement of the lining. The strips are placed near the surface of the concrete to ensure that the crack which forms will extend from the top of the strip to the canal lining surface. The strip then acts as a waterstop. If the strip is tilted during installation the crack may form from one of the lateral bulbs, reducing the value of the strip as a waterstop, and if a crack forms at the bottom fin and extends to the surface all benefits of the strip are lost. The first installation of the molded strips by the Bureau of Reclamation was in the San Luis Canal. Requirements for the San Luis Canal,
which flows up to 30 feet deep and produces high heads on cracks in the canal bottom, prompted the present investigation. Some of the seal strips developed to date are shown approximately to scale in the following figures:

![Diagram of Constop strip](image)

**The Constop strip, Figure 1, is made of extruded polyvinyl chloride by Edoco Products.** This strip gives some vertical restraint against slab displacement and will allow slab separation of approximately one-fourth inch, but produces undesirable tension in the strip. First placement of Constop strip by the Bureau of Reclamation was in a 4,000-foot length of canal in Reach 2 of the San Luis Canal. The strip, carried on a spool on the paver jumbo, was installed longitudinally in the canal about one-half inch above subgrade. This depth proved unsatisfactory since random surface cracking, and not controlled straight cracking, resulted. The random cracks then required surface sealing. Later placements made with the Constop nearer the surface have eliminated the random cracking, resulting in a controlled crack and a relatively watertight joint. The use of Constop transversely in the canal has not proven entirely satisfactory. If the transverse strips were placed before the paver passage, the strip was generally left in a slanted position in the concrete.

This produced cracks from the bulbs on the strip and, to a great extent, nullified the sealing effect of the strip. However, when the strips were properly placed, both longitudinally and transversely, they have proven very satisfactory. Construction of a satisfactory crossover requires dipping one strip beneath the other, snipping off a portion of the vertical fin on the lower strip, or both.

Longitudinally placed Constop strips used in combination with polysulfide-filled transverse grooves also have produced very effective watertight construction. Tests on the overall effectiveness of Constop have not been made. A few tests on isolated crossover intersections have been made.
with the canal and the subgrade dry, but these are not representative of the conditions to be encountered when the canal is full and subgrade conditions have stabilized. More meaningful tests could be performed on Reach 4 of the San Luis Canal if planning for these tests is started before the canal is filled.

The Dill Strips, Types 1 and 2, Figure 2, also of plastic, were designed by Mr. Robert F. Dill and were installed on a trial basis in Reach 2 of the San Luis Canal. The installation of Type 1 has not proven entirely satisfactory since it is adaptable to only hand methods. Like the Constop Strip, excessive movement of the slabs due to crack opening might produce excessive tension within the strip. The Type 2 strip which is more flexible than Constop or Type I Dill Strip includes an accordion fold which permits relatively large openings and/or vertical displacements between contiguous slabs. The plane of weakness produced in the concrete is partially accomplished by a thin sheet of plastic extending vertically upward from the fold. The plastic sheet is cut at joint intersections to allow a relatively unimpeded crossover of the longitudinal and transverse strips. This cutting works well except when the sheet is inserted under excessive tension. Cutting then permits the sheet to contract and it then fails to form a continuous plane of weakness. Type 2 strip adapts to installation methods similar to those used with Constop.

The strip shown in Figure 3 was manufactured by the Goodrich Rubber Company to be installed by the Peter Kiewit Sons' Company in Reach 3 of the San Luis Canal. This polyvinyl-chloride strip consists of a three-bulb horizontal member for sealing and a vertical member for crack formation. Difficulties were encountered in placement, but the strip proved to be quite successful after the installation problems were solved. This strip, like Constop and Dill Type 1, does not provide for lateral movements of adjoining slabs without high tension on the strip.
The USBR proposed strips, Figure 4, which are similar in principle to the previously mentioned strips, were designed by Bureau of Reclamation personnel. The shapes are an outgrowth of developmental work to produce a strip with good sealing and easy installation characteristics, and superior ability to accommodate large slab movements and displacements. The strip has not been used to date in Bureau constructions.

USBR mastic sealer, Figure 5, is a single component, rubberized asphalt material that has, in general, given fairly good results in wide usage in Bureau canals for several years. It is low in cost, has good adhesion to wet and dry concrete, and has good durability where protected against weathering. However, age and exposure to weathering
eventually produce hardening, cracking, and failure to act as a sealer.
Also, this material is initially soft enough to be extruded through small
(1/16-inch-wide) cracks under high heads (deep canals). In such cases
it is necessary to provide a backup material under the mastic in the
grooves as shown in Figure 6.

Construction difficulties in placing the backup material (sponge rubber
rod) resulted in installation of this type of seal in only parts of the first
two reaches of the San Luis Canal.

Experience and testing has indicated that grooves filled with polysulfide
material, Figure 7, appear to be promising. The State of California
has reported excellent results from tests on a coal-tar modified poly-
sulfide. This material was substituted for the USBR mastic placed
above the sponge rubber rod in the contraction joint specified for the
grooves for about 1 mile of Reach 1 of the San Luis Canal. Later as
experience was gained, this material was also used to seal invert
grooves in Reach 1, San Luis Canal, as shown in Figure 7. Laboratory
testing of this material in cooperation with Thiokol Corporation has been
very intensive and the results are quite promising. The short-term
tests indicate excellent properties particularly in regard to weathering.
Adhesion to dry concrete is excellent and more recent tests indicate that variations of the composition of this material may be made to improve adhesion to freshly poured concrete. Specifications tests require that the polysulfide resist extrusion through a 1/8-inch-wide crack under a 60-foot head of water maintained for 7 days. Thus no rubber rod backup appears necessary. Field testing periods have extended over only a short time; therefore, long-term durability properties of this material are not known. The first field installations on San Luis Canal appeared satisfactory; the material was well bonded to the concrete and exhibited the expected physical properties. Inspections made after the canal was filled with water indicated air pockets in some of the extruded material. The extent of these deficiencies or their effects on water losses has not been determined.

Continuing efforts to solve the problems of optimum shape of joint, type of seal strip, and installation methods are being made by both the Bureau, manufacturers, and contractors with excellent chances for success. At the present time, both longitudinal and transverse seal strips can be used together successfully in the slabs of 3-inch minimum thickness. In slabs less than 3 inches thick, a longitudinal seal strip used with transverse grooves sealed with polysulfide (or other suitable material) has been successful.
RANDOM CRACK SEALING

Major random cracks in concrete canal lining are primarily the result of stresses induced by various external forces. These forces may be produced by changes in the subgrade resulting from subsidence, heave caused by frost action, expansive clays or shales, dry subgrade, or back pressure from water trapped behind the lining of an unwatered canal. Cracks resulting from these causes are not predictable and sometimes occur even though appropriate countermeasures have been taken to control a potentially detrimental situation. Present practice requires that these cracks be sealed.

Minor random cracks are those, superficial in nature, that generally do not completely penetrate the slab until a long period of time has elapsed. They result from chemical reactions and weathering previously discussed in the section dealing with causes of cracks. Sealing of these cracks is generally not feasible.

For some years subsequent to the conclusion of World War II, cracks in the preformed grooves were sealed by filling or partially filling the groove with a two-component mastic sealing material developed in the Bureau of Reclamation laboratories. This same material, in addition to hot asphalt and/or emulsions was presumably used to seal random cracks. However, the practice of sealing random cracks was not widespread and it is believed that most remained unsealed. Difficulties in obtaining quality raw materials for the mastic, such as asbestos and other components, and apparent inability to obtain a uniform final product were encountered, and by 1952 the practice of sealing cracks was abandoned. In 1955, the practice of sealing cracks in grooves was re-instituted and the sealing of random cracks followed closely.

The following materials have all been used in experimental crack sealing applications with varying results:

1. Polysulfide rubber;
2. Ram-Nek tape, a fabric-reinforced heavy body rubberized asphaltic mastic with a thin film of polyethylene on the exposed face;
3. Polyurethane rubber;
4. Silicone rubber;
5. Flexible epoxies; and
6. Rubberized asphalt.

The first two listed materials are considered to be superior to the others listed and are currently recommended.

Polysulfide rubber sealer, Figure 8, previously described under Controlled Joint Cracking and Sealing, is well adapted to sealing of random cracks, and has been specified and installed in joint grooves in the San Luis Canal. Performance of this field installation to date has been satisfactory and the same performance is expected when used to seal random cracks.
Ram-Nek tape, as installed, Figure 9, is composed of four layers: (1) a light polyethylene film on the exposed surface, (2) 1/16-inch mastic, (3) woven fiber glass fabric, and (4) 1/8-inch mastic. Before application, the tape is covered with paper to protect the 1/8-inch layer of mastic which serves as the adhesive. This tape has not yet been specified for use in project repairs, but experimental installations were made as far back as 1962. Inspection of installations on linings of the North St. Vrain Feeder Canal in the fall of 1966 showed Ram-Nek
tape to be in excellent condition, well bonded, and the mastic still in a plastic state. Coincidental installations of polysulfide rubber were found also to be in excellent condition.

Continuing efforts by both the Bureau and materials formulators, both in the laboratory and in the field, are being made to develop and evaluate new compounds with better adhesion, longer life, and greater resistance to weathering. The ultimate in these materials would be one with the above characteristics and, in addition, the ability to bond to moist concrete surfaces, either fresh or hardened. Representatives of Thiokol Corporation have discussed with Bureau personnel a material that will bond properly when placed in fresh concrete. They are furnishing the Bureau laboratory a sampling recently placed in the test area of the San Luis Canal under State of California jurisdiction. (See minutes of Special Meeting, January 5, 1967, in Appendix.)
JETTING AND GROUTING BEHIND CONCRETE LINING

Another method of increasing watertightness of existing concrete canal lining is through jetting and filling the voids with a relatively lean (1:6 or 7) portland cement-sand grout. With care, little bulging or heaving of the slabs is experienced and reduction of seepage is obtained. This method, which requires no heavy equipment, can efficiently be used by project or O&M personnel. One installation used 1,132 sacks of cement and 192 cubic yards of sand and cost $5,000 per mile.
REDUCTION OF SEEPAGE THROUGH SUBGRADE PREPARATION

Other methods for reducing seepage through random and contraction joint cracks have been considered and have been used for some installations. The compaction, in place, of subgrade soils, prior to placing concrete lining, will reduce seepage losses. For beneficial results the natural soils must contain adequate amounts of fines. Experimentation with compaction equipment to produce in-place compacted depth of about 2 feet is in progress. Where the natural soils are coarse and pervious, fine borrow materials can be placed and compacted on the natural subgrade prior to placing concrete lining, but at additional expense.

Asphalt membrane, sprayed on the subgrade prior to placing concrete lining has been used in a few instances and plastic sheets have been considered. These materials reduce the friction of the lining on the subgrade and thus fewer, but wider, cracks are formed.
GUEST SPEAKERS

The authors wish to express their appreciation of the time and effort expended by the following named guest speakers. Their knowledge and recounted experiences have been of inestimable value to the Team in gaining a more intimate insight into the various phases of the problem.

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
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<tbody>
<tr>
<td>L. M. Ellsperman</td>
<td>Head, Bituminous and Petrochemical Section</td>
</tr>
<tr>
<td>P. W. Lewis</td>
<td>Head, Coatings, Sealers, and Plastics Section</td>
</tr>
<tr>
<td>J. L. Kiewit</td>
<td>Materials Engineer, Chemical Engineering Branch</td>
</tr>
<tr>
<td>H. Johns</td>
<td>Materials Engineer, Chemical Engineering Branch</td>
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<tr>
<td>W. G. Holtz</td>
<td>Assistant Chief Research Scientist</td>
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<td>F. E. Rippon</td>
<td>Chief, Canals Branch</td>
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<tr>
<td>E. W. Ryland</td>
<td>Chief, Construction Supervision Branch</td>
</tr>
<tr>
<td>R. J. Willson</td>
<td>Chief, Maintenance Engineering Branch</td>
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<tr>
<td>J. V. Walker</td>
<td>Maintenance Engineering Branch</td>
</tr>
<tr>
<td>E. C. Higginson</td>
<td>Chief, Concrete and Structural Branch</td>
</tr>
</tbody>
</table>
SELECTED REFERENCES (ANNOTATED)

1. Concrete Laboratory Report No. C-614, March 1952. Results of tension tests of waterstop material and joint, transverse and longitudinal shear, and permeability of joint are reported.


3. Linings for Irrigation Canals—U.S. Interior Department, Bureau of Reclamation—1963. All phases of canal lining and sealing are presented.


8. Memorandum, Head, Canals and Drainage Section; Chief, Canals Branch; Lloyd F. Weide, Civil Engineer to Files, June 28, 1966. Groove sealant for buildings and canal linings, and crack control devices are discussed.


10. Letter, Project Construction Engineer, Los Banos, California, to Chief Engineer, August 5, 1966. Letter reports on random cracking of concrete canal lining with polyvinyl chloride waterstop placed 2 inches below the surface.

12. Joint and Crack Sealing in Concrete Lined Canals, informal discussion authored in Coatings, Sealers, and Plastics Section, October 21, 1966. Discussed are all phases of joint and crack sealing.

13. Travel Report, J. L. Kiewit, October 27, 1966. This reports on a meeting with California Department of Water Resources personnel regarding contraction joint sealing in the San Luis Canal.


17. Letter, A. R. Golze, Chief Engineer, California Department of Water Resources to Chief Engineer, Bureau of Reclamation, February 15, 1967. Use of polysulfide sealant in fresh concrete grooves is discussed.


APPENDIX
Appendix

MINUTES OF FIRST MEETING HELD BY V. E. TEAM NO. 11

October 11, 1966

The first meeting of Team No. 11 was an organizational meeting and was held with Messrs. Harold Martin, Elmo Higginson, Graydon Burnett, and Bill Wolf also in attendance. Mr. Wolf gave a history of the Value Engineering Program in the Bureau and outlined the problems to be worked on by the team. The problem as presented by Mr. Burnett and approved by the Chief Engineer for a Value Engineering Study was stated as follows:

"Methods of Controlling and Sealing Contraction Cracks in Concrete Canal Lining"

Mr. Burnett further stated that the subject for study concerns the problem of providing effective and economical control of cracks in concrete linings and making the linings watertight. He said that a variety of techniques and materials have been tried but we still do not have the solution for which we are searching. This is most graphically illustrated by the problems we have been having on the San Luis Canal. He emphasized that the potential benefits of a V.E. study, if successful, could provide possible savings and better performance of concrete linings. The team was instructed to submit reports to Mr. Burnett on our progress every 2 weeks.

Following this indoctrination, all except the team members left the meeting room and the team was on its own. Mr. A. J. Peterka was elected Chairman; Messrs. Jim Backstrom and Harry Broughton, recorders.

It was agreed to meet on Wednesdays at 8:30 a.m. every week until completion of the assignment. Also, the Chairman emphasized that the V.E. work has a top priority and that regular attendance at meetings is absolutely necessary for all members of the team. Minutes will be kept of the meetings and copies of these minutes will be supplied by the recorders to team members as soon after the meeting as possible. The chairman will prepare the reports to Mr. Burnett. A final report on the team's findings will be prepared in a team report.

In discussing controversial items, it was unanimously agreed to refer only to methods of procedures that have been used and not to the individuals who have used them. Members of the team agreed to start collecting materials which is believed will be germane to the problem on hand. The exact problem to be studied by value engineering methods could not be stated at the moment. It was decided to give this matter further study; to examine the scope of the assignment. To do this it will be necessary for the team members to acquire background information on broad aspects of the
overall subject. The team felt that we should listen to the words and advice of some of the experts working on various parts of this general problem and then determine from their remarks what the exact problem is and what to do about it.

MINUTES OF THE SECOND MEETING
October 19, 1966

This meeting was devoted primarily to a general discussion of canal lining contraction joints, joint sealing materials, and waterstops. Highlights concerning the lining including canal size, depth, lining thickness, etc., were discussed. In general, joints are installed to isolate slabs 12- to 15-foot square. Linings vary from 2 to 4 inches in thickness. Grooves, if employed, are formed to approximately one-third the thickness of the concrete slab. In the use of waterstops the longitudinal stop is placed near the bottom of the slab and the transverse stop is placed near the top. A joint seal which utilized Constop plastic strip, made by Edoco, was discussed. Such a stop when used in 15-foot squares has 720 inches of joint length and is effective for all of the length except a 2-inch length where the transverse and longitudinal seal strips cross. At this point cracking occurs in such a manner that the effectiveness of both the transverse and longitudinal strips are nullified to a great degree. Relatively large water losses have been measured at the crossover points. Despite this weakness the seal is claimed to be over 99 percent effective. Also reviewed was a talk given by Dr. Lee Worsom of Edoco Products on September 22, 1966, in the Bureau offices. He described and showed slides of their equipment and installation processes. He said they had hired experts in several fields to improve their Constop layer, Constop waterstop, finishing process, etc., and had hundreds of thousands of dollars tied up in their business. He said they are still operating in the red. Dr. Worsom said they were placing 50,000 lineal feet of Constop a day on a 4,200-foot reach of the San Luis Canal. He indicated that the cracks at the crossover points (mentioned above) tend to swell closed after the concrete becomes water soaked with the canal in operation. He felt that sediment would seal the narrow crack remaining (after expansion) and prevent water loss. Hydraulic tests, which put 30 feet of head on several selected crossover areas (before water soaking), showed seepage rates of up to 50 gallons per hour. These tests were conducted by an independent testing laboratory hired by Edoco. More tests showed considerably less water loss, however; but no certain value has yet been obtained. In general, there are mixed feelings among test observers whether the seepage rate is large or small, whether the cracking at the crossover is extremely important or only somewhat so, and whether Constop can be installed in a consistently satisfactory manner at a satisfactory price.

Various other materials for sealing joints were discussed among which were polysulfides, silicones, and clay. The polysulfides are claimed by some to be a relatively expensive material. Consequently, the
amount that can be used economically in a joint may need to be limited. Silicones are even more expensive. Silt borne by the canal water is believed to be effective in sealing cracks of 0.02 inch or smaller if there is backup material behind the crack to prevent flow through. One of the big difficulties in sealing a crack or joint is getting an adhesive that will adhere to both surfaces when the concrete or joint is wet. It was suggested possibly that 3-M Manufacturing Company, or others, might be consulted for such an adhesive.

MINUTES OF THE THIRD MEETING
October 24, 1966

This meeting was devoted to a continuation of general discussions of canal lining, joints, joint sealing materials, and waterstops. Experts in this field were present, Messrs. Ellsperman, Lewis, and Kiewit, each of whom contributed many facts and some historical background. Sealing compounds, asphalt, and plastic coatings on subgrades, and the costs of various materials and processes were discussed. Sprayed asphalt coat on the subgrade, the asphalt being similar to that of roofing asphalt, costs $0.50 per square yard. Buried asphalt membrane costs between $0.26 and $0.50 per square yard. Ten-mil-thick PVC film costs about $0.45 per square yard. All of these methods would seal the canal in its entirety. It has been proposed under a concrete slab to use plastic strip anchored to the subgrade at the joint and to use mastic to stick the plastic to the fresh concrete. Other items of interest discussed included:

1. better adhesives are available for joining neoprene than for butyl;
2. neoprene is more expensive than polysulfide,
3. silicone sealing compounds are the elastic type and cost approximately $15 per gallon. Both neoprene and silicone would remain under tension in an opened joint,
4. polysulfide is a visco-elastic material and loses stress when retained in a stretched position (stress relaxation is considered to be a desirable property).

A speculation was discussed that the values of water which are increasing all the time will soon cause the employment of covered canals or pipe systems which would eliminate weeds, evaporation, etc. Another item discussed was the finding and evaluating of water losses from conveyance structures. Methods for determining the extent of leaking areas of a canal are needed. Pinpointing of leaks would be desirable if a fast economical method could be found.

MINUTES OF THE FOURTH MEETING
November 2, 1966

During this meeting, Mr. Jack Kiewit showed some very informative slides of canal lining, joint preparation, and crack repair, mostly on the San Luis Canal. He discussed at some length the forming and
preparation of wye joints and the presently used method of sealing, using butyl or neoprene sponge rope to prevent extrusion of Bureau of Reclamation mastic filler material. After this presentation there was a general discussion to clarify some points of the joint makeup.

MINUTES OF THE FIFTH MEETING
November 15, 1966

This meeting consisted of a field trip to observe placement of sealants and sealants in place in an existing section of canal on the Colorado-Big Thompson Project. While waiting for the sealant manufacturers to make their preparations, the team inspected various sealants which had previously been applied to cracks and preformed grooves in the concrete lining.

Of the sealants (already in place for an appreciable time at the time of the team's visit) on random cracks, Ram-Nek tape (a glass fabric reinforced asphalt mastic tape) appeared to have retained its adhesive and plastic properties to the best degree. Of the "in place" sealants placed in preformed grooves, polysulfide appeared to be in the best condition.

The team witnessed application of Ram-Nek tape on random cracks, the surfaces around which had been prepared in varying degrees: no preparation, sandblasted, primed and not primed, heated and jet cleaned by a butane heater, and various combinations of the above. Some of the Ram-Nek was applied to cracks which had free moisture in the concrete. At these locations, the Ram-Nek did not bond. Polyurethane sealant was then applied in preformed grooves where normal cracking had occurred. This material, as hand applied, was rather messy and time consuming. The team was told that the machine application is a much cleaner and smoother operation.

MINUTES OF THE SIXTH MEETING
November 21, 1966

Discussions were held on the field trip of November 15, 1966, concerning the various sealant materials observed in place and in the process of being installed.

One of the members gave a resume of a meeting he attended at which General Electric Company representatives described silicone sealants and roofing materials. The description included design procedures and application methods for the various materials. One of the representatives stated that a material was being developed for release within a year and believed that this material would be suitable for sealing wet joints below the water surface.

The remainder of the meeting was devoted to an appraisal of the team's progress and an attempt to chart our future course. Guest speakers will be invited to talk to the team regarding their specialities in the crack sealing problem.
Three guests, Messrs. Paul Lewis, Jack Kiewit, and Henry Johns, led a discussion concerning the printed material given to us at the October 24 meeting. Questions on relative costs of various sealants were explained; also, a clarification on the installation of "Dill" Strip was given.

Jack Kiewit explained that bleeding of concrete could possibly cause bond trouble on polysulfide sealers installed in fresh concrete, but has not in the test work performed to date. Thiokol presently has offered us a polysulfide with properties allegedly superior to the California DWR material when installed in fresh concrete, but it is also a quick-setting sealant. Advantages of a slow-setting sealant were explained. The present (DWR) polysulfide sets appreciably within seconds; this can cause equipment cleanup problems on small jobs or with inexperienced applicators. Thiokol is now developing a slow-setting polysulfide, and the Bureau is delaying testing until we hear how it is coming. (It was learned weeks later that there was some misunderstanding between Thiokol and the Bureau on this point.)

In locations where canals are in pervious material and leakage water after passing through a joint can escape rapidly, it may be desirable that crossovers of "Constop" be sealed tighter since the leakage rate may be appreciable. However, the overall seal obtained with "Constop" is undoubtedly much better percentagewise than we generally have obtained in the past. If the subbase is impermeable, the loss of water through crossovers is unimportant as little of it can escape; although the water presumably could cause damage if the subgrade were expansive clay.

Canal leakage into permeable lenses in a generally impermeable material may cause trouble because during rapid unwatering of the canal, the lining may be pushed out. This is apparently the reason a sealer was required in impermeable areas of the San Luis Canal. For this reason, the Columbia Basin has a rule to lower canals only 1 foot in 24 hours to avoid these unbalanced back pressures.

Soluble materials in the subgrade cause problems when leakage occurs. In the citrus groves of California, it is essential that boron in solution be prevented from contaminating the canal water, therefore, leakage has to be pumped or drained away from the canal. Flap (check) valves cannot be used in these locations.

Mr. Paul Lewis stated that the costs of sealants have not been stabilized, nor is their price truly reflected in bid items. He cited the case of negotiations with the contractor (M-K, prime contractor, and Mulleneau, subcontractor) for sealing cracks in San Luis Reach 2. The subcontractor wanted $0.51 per lineal foot which was more than that bid on Reach 1. A separate contract (DC-6470) was then awarded on the Reach 2 work for $0.2925 per lineal foot; Mulleneau's bid was about $0.34 per lineal foot,
after apparently turning down a negotiated figure of about $0.41 (approximately that bid on Reach 1). Mr. Jack Kiewit stated that the material cost of polysulfide is basically high, compared to the Bureau's mastic, because of expensive raw materials.

As a result of observing many samples of silicone sealant, Mr. Henry Johns feels that silicones are relatively expensive, $35 per gallon, and have bad bond failures when exposed to water, especially where the water can get around the sealant, such as through the pores in concrete.

In general, the overall costs of the several basically different sealing systems may prove to be fairly similar, although the performance of these systems probably varies widely.

Failure and breakdown of concrete observed adjacent to random cracks in the St. Vrain Canal were mentioned. It is believed that, while sealing may contribute to this by keeping moisture in the cracks and thus subjecting the concrete to more freeze-thaw cycles than in relatively dry cracks, the actual effect was probably small.

Following is a list of ideas presented for improving canal sealants and methods:

1. Possible development of sealing strips which would act as a sealant against canal leakage but would also relieve back pressures on the underside of the canal.

2. Possible development of flap valves which could easily and cheaply be installed at joint intersections with the remainder of the joints to be sealed tight.

3. Improvement of installation methods for "Ram-Nek" tape for sealing random cracks to insure reliability of obtaining the good performance demonstrated in the St. Vrain Canal and to reduce costs.

4. Evaluation of the merits and costs of a subgrade liner, such as sheet butyl or a similar material, to be laid ahead of concrete lining. All joints in the liner to be sealed forming essentially a "bottletight" canal. Relief from back pressure might be provided by flap valves sealed to the liner.

5. Conduct of major contraction joint field tests to evaluate sealing systems and materials before the need for them in a large canal is urgent.

6. Investigation to determine how much a canal lining slab must be weakened to insure crack control; that is, what fraction of the lining thickness must be weakened at joints.
MINUTES OF THE EIGHTH MEETING
December 7, 1966

The guest speaker for this meeting was Mr. Lewis Ellsperman.

Mr. Ellsperman first presented the team with a copy of Report No. RR 118 of the Department of Highways, Ontario, Canada, on "Evaluation of Field-moulded Sealants for Concrete Pavements and Structures" of October 1966. Chairman Peterka read aloud from the conclusions of the report and a discussion followed with Mr. Ellsperman as moderator. The report, in general, stated that no present sealant could be expected to perform properly for longer than 2 years. This report is evidently counter to results found by the California DWR which has stated that two-component polysulfide is a satisfactory material. These differences warrant considerably more study by the team. The report will be circulated among the team members for their personal examination and study.

Mr. Ellsperman continued his discussion with descriptions of butyl underlayment on the Delta-Mendota Canal and Shoshone Canal. In both instances the butyl has provided a satisfactory "bottletight" lining. He continued by describing canal installations using polyvinyl-chloride plastic, 10 mils thick at $0.42 per square yard. This plastic was installed in canals carrying greater than 35 cfs with gravel over the plastic to hold it in place and protect it from the sun. Over 140,000 square yards have been installed near Tucumcari in canals too large (35 cfs) for the slip-form paver (too large on this project only) to place a concrete lining.

Overlapping this sheet plastic from 18 inches to 3 feet appears to provide watertight joints without using an adhesive. It is possible, on installations where back pressure may occur, that some sort of relief valve will be required for canal stability.

Polyvinyl-chloride sheeting cannot be left exposed to sun and weather. No installation has been properly made as yet with concrete lining over the plastic. Test sections have been made in Utah, but difficulties were found in preventing the plastic from creeping along with the paver, stretching, and possibly tearing underneath the concrete. Discussion of the material presented by Mr. Ellsperman followed. He left the meeting because of an urgent appointment.

To clarify some of the remarks made by previous speakers, Chairman Peterka explained the nomenclature and difficulties experienced in testing canal reaches to determine leakage. Methods covered included Bureau seepage meters, ponding tests, and electrical logging. He stated that in general leakage of greater than 1/2 cfd is considered sufficient by the Bureau to warrant sealing procedures on the canal lining. In some instances leakage of 10 to 15 cfd has been measured. Leakage measurements vary considerably with variations in soil, evaporation, amount of bank storage, type of subgrade, and/or lining, etc.
Measurements by seepage meters which evaluate only 1 square foot of surface at a time can vary as much as 1,000 percent in different but nearby locations along a canal.

MINUTES OF THE NINTH MEETING
December 14, 1966

Guest speaker at this meeting was Mr. Wes Holtz who gave a resume of the costs and use comparisons of various types of canal linings.

Approximately 24 million square yards of concrete lining are in place. As examples, the average cost (to 1963) varied from $3.70 for 3-1/2-inch-thick unreinforced down to $2.10 for 2-inch-thick unreinforced. The cost of unreinforced lining in San Luis Reach 3 was $2.40 per square yard. Average cost of 4-1/2-inch-thick reinforced lining was $9.50 per square yard.

Approximately 6 million square yards buried asphalt membrane lining have been placed. The average cost varied from $1.10 per square yard for earth or gravel covered membranes to $2.60 for shotcrete covered membranes. This has been installed mostly on medium to small canals. In other small canals, approximately 100,000 square yards of buried plastic sheet has been installed at an average cost of $0.75 per square yard.

Approximately 12 million square yards of thick earth lining have been installed at an average cost of $0.84 per square yard to a low of $0.50 per square yard on the larger canals, such as the Delta-Mendota, where the length of haul was cut to a minimum.

Various waterborne materials such as SS-13, Chevron, bentonite, and sodium carbonate have been used to waterproof earth subgrades for a short period of time, but they do not perform satisfactorily over long periods. Tests are presently being made on below surface installation of grout or asphalt to form an impermeable layer.

Subgrade materials often determine canal seepage rates. Generally speaking, most canals require lining if the seepage rate exceeds 0.5 cu ft/sq ft/day. Lined canals should achieve a seepage control of at least 0.1 cu ft/sq ft/day.

Mr. Holtz presented a series of photographic slides of canals, showing various types of lining failures and design details on the San Luis, Friant-Kern, Gateway, and other canals. A section through a portion of the Gateway Canal placed over an expansive clay subgrade showed construction details such as catalytically blown asphalt on subgrade, 14-inch thickness of pervious material leading to a drain, and 4-inch concrete lining. This is an expensive installation but has performed excellently in carrying the 1,000 cfs canal through the reach of troublesome soils.
A design cross section of the San Luis Canal was shown for fat clay areas, with an explanation of various zones and their compaction methods. Mr. Holtz also explained the use of "liquid limit" test values for selecting the various zone materials. Areas of embankment adjacent to the canal prism were to have a liquid limit less than 40 to limit expansiveness.

Slides were shown of settlement ponds used by the Bureau on the San Luis Canal. A cost of approximately 1-1/2 million dollars was given for Reach 3 ponding (to achieve subsidence). Ponding presettles the foundation in shallow subsidence areas by consolidating a low-density material. Shallow subsidence can cause difficulties to rigid linings.

Another problem on the San Luis Canal was deep subsidence which occurs from water withdrawal due to wells. Deep subsidence occurs over a large area and does not cause local cracking of lining, but does require allowance in canal grade and structures. Up to 16 feet of settlement has occurred in the subsidence basin in the southwestern part of the San Joaquin Valley.

Other causes of lining failures are frost heave and foundation piping for both of which pictures were shown. Other slides showed construction of thick and thin compacted earth linings, the thick being approximately 3 feet normal to the slope, 10 to 12 feet horizontal thickness, and the thin about 18 inches normal thickness. The best materials for earth linings are impervious gravelly materials which provide both control of seepage and control of erosion.

### Comparison of Concrete, Thick Compacted Earth, and Asphalt Canal Lining

<table>
<thead>
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<th>Property</th>
<th>Concrete</th>
<th>Thick Compacted Earth</th>
<th>Asphalt</th>
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<tr>
<td>Seepage</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Erosion</td>
<td>Excellent</td>
<td>Good (with good construction practices)</td>
<td>Recommended protective coatings for erosion under operating conditions</td>
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<tr>
<td>Appearance</td>
<td>Good</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Serviceability</td>
<td>Excellent</td>
<td>Good (with normal subgrade conditions)</td>
<td>Excellent</td>
</tr>
<tr>
<td>Moving subgrade</td>
<td>Fair to Poor due to cracking</td>
<td>Excellent</td>
<td>Excellent</td>
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</table>
Costs.--Concrete "high"; earth "low"; asphalt "medium" to "low" (on large canals). Note: It is also necessary to have a "large" canal before earth lining costs are "low."

Back pressures.--Concrete "good"; earth "excellent"; asphalt "good." Both concrete and asphalt lining require drains, or with the asphalt lining, weight of cover may be thickened to balance the hydrostatic back pressures.

Putah South Canal was cited as an example of pervious subgrade aiding canal seepage. On portions of this concrete-lined canal an underdrain was provided. The underdrain has been completely full when the canal is operating.

In expansive clay subgrades, it is necessary generally to replace expansive soils adjacent to the lining with nonexpansive soils or to use an impervious membrane underlining. On the Friant-Kern Canal, asphalt was used in some experimental reaches under the concrete. This seems to have prevented major slides and heaving. The Gateway Canal example shows the best, but most expensive, method of subgrade control. Mr. Holtz believes an asphalt underlining is more expensive than the new joint materials such as Constop, etc., but would provide protection from seepage through random cracks. If the subgrade soils contain some fines, compaction of the subgrade will reduce seepage losses through cracks in the lining. Another method of eliminating seepage might be by providing a subgrade seal at concrete lining joints by grouting. A draft form report on the use of AM-9 (a jell) is in existence but shows little promise on the use of this material at present.

Soil cement linings have been used with varying degrees of success. The very first at Altus Project used a concrete mixer. The material was compacted in place 4 to 6 inches thick. This was a clayey material and did not prove satisfactory. Through a donation of cement by the PCA, the sandy soils of the West 11 lateral at Altus was soil-cement lined, and various materials used as curing compounds.

The soil cement used was a "plastic" mix and was very satisfactory where proper cement to soil ratios and curing compounds were used. It still is good after 15 years.

On the New York Canal another plastic mix was used, making a low-density material--about 80 pcf--which has been satisfactory and in place for 20 years. In the Columbia Basin on West 20 lateral a mixed-in-place facing was used but was replaced after only a short time. Construction methods used under a change order were poor. On several recent earth dams, facings of soil cement have been installed and are satisfactory.
Mr. Holtz believes that a plant-type mix is necessary for canal linings of soil cement. Soil cement is relatively expensive, roughly $1.60 a square yard (6 inches thick) compared with compacted thick earth linings. We probably have the "know how" now for constructing acceptable soil cement linings.

MINUTES OF THE TENTH MEETING
January 4, 1967

Guest speaker at this meeting was Mr. Frank Rippon who lectured on past and present practices in sealing joints in concrete canal linings.

Mr. Rippon presented comprehensive history of joint construction in early concrete linings when hand labor with screeds was employed to finish the concrete. Most linings at that time were placed in alternate panels, utilizing "heads" at the panel ends for forms, and have proven very successful.

With the advent of slip-forms and other mechanical pavers, the design of joints was changed to accommodate mass production methods and obtain lower cost linings. Mr. Rippon stressed the need of coordinating joint design with construction procedures to eliminate wasteful operations. As an example, the use of preformed plastic groove forms has eliminated labor required to sandblast grooves before placing joint sealant materials. This has been true to a certain extent on some jobs, but considerable effort was required on the San Luis Canal to remove the plastic forms. This partial failure may, in turn, be leading to a greater use of the "Constop" type of joint sealant (waterstop).

Mr. Rippon believes that very little differential vertical movement of adjacent slabs occurs at joints; therefore, the design of joints should consider that the major movement of the slabs is due to contraction and expansion of the lining panels; only slight allowance should be made for the offsetting of joints. He suggested that possibly a survey should be made to determine actual movement at joints.

Concrete lining is placed in thicknesses varying from 2-1/2 inches to 4-1/2 inches. Most of the thinner linings are placed by use of a subgraded slip-form which is one utilizing the subgrade to support and guide the paver.

Approximately 160,000 feet of "Constop" was placed with the material adjacent to the subgrade instead of near the surface as intended. Joints made in this manner did not crack in the proper place; therefore, the "Constop" was ineffective as a water seal. Later installations with the "Constop" near the lining surface provided a satisfactorily cracked joint. A question was raised as to the performance of waterstop material the same thickness as the lining. Mr. Rippon stated that this would
work satisfactorily in longitudinal joints but that the joint material would be displaced in transverse joints by the action of the paver which would leave the joint material in a slanted position. Waterstop of the same thickness as the lining if installed in transverse joint would interfere with the flow of concrete from the paver.

In 1938 the Bureau installed 6-inch rubber dumbbell waterstop with an elastic joint filler in an exposed concrete flume on the Provo Project. Later the center bulb type of waterstop was developed for use in joints where possible offset movement is expected. This type of waterstop eliminated the need for joint filler as the center bulb provides a place for the incompressible rubber to occupy during joint movement.

On the question of the necessity for providing bottletight linings, Mr. Rippon feels that when concrete lining is used, it should be made as watertight as practical with provisions for back pressure relief valves where necessary. He also believes that random cracking occurs in isolated areas, is caused by foundation problems that have been designed for as well as possible, and is an O&M problem. He believes that concrete lining is much better than an earth or membrane lining for the following reasons:

1. Concrete lining is cheaper for O&M in that it is easier to clean and dries quicker to kill algae and phreatophytes.
2. Concrete lining is safer in cases where cracks develop in foundations and embankments due to earth movement and settlement.
3. A smaller net cross section is required because "n" is more favorable. Also, larger velocities are possible without danger of erosion of the canal banks and bottom.

Mr. Rippon recommends use of an accordion type of waterstop to eliminate putting the waterstop into direct tension upon opening of the joint. He also believes all waterstops should have a minimum effective life of 50 years, coinciding with that assumed for all canal structures. The cost of sealants and waterstops should be less than $0.50 per lineal foot, preferably about $0.25 installed.

Mr. Rippon feels that the USA is ahead of foreign countries in canal lining progress, possibly because their material costs are so high in relation to labor costs. He did advocate use of one Mexican development. This is use of a soil-cement pad under concrete linings through rocky permeable areas. The soil-cement pad would not be susceptible to piping of fine materials into the subgrade which has occurred in some American canals.
SPECIAL MEETING  
January 5, 1967

Three team members attended a lecture by Mr. Ernest R. Sutton, Canal Project Manager for the Thiokol Chemical Corporation. Also in attendance were approximately 15 other members of the Chief Engineer's staff.

Mr. Sutton showed movies and slides of installation procedures of a new polysulfide compound in a concrete canal lining. This compound is a two-component polysulfide sealer mixed in the applicator gun head and has the ability to bond to fresh unset concrete. The sealer must be placed within approximately 30 minutes after concrete placement. The formulation can be changed slightly and the sealant will then bond with hardened dry concrete. Hardened wet concrete does not have free cement available to the fresh sealer to provide a necessary chemical reaction to create bond.

Present installation of this new compound is limited to approximately six transverse joints of the San Luis Aqueduct. Processes for inserting this compound in fresh concrete consist of the following:

1. Initial forming of the joint in the fresh concrete lining by a knife edge.

2. Insertion of a plastic joint form into the joint, local vibration of the joint to consolidate concrete around the form, then immediate withdrawal of the plastic form in a continuous process.

3. Insertion of the compound by a combining nozzle which is attached to a metal blade. This blade reopens and reforms the joint immediately ahead of the nozzle.

Mr. Sutton explained that this new compound has a "pot life" of 30 seconds or so, and this short "pot life" is a major factor in making successful canal lining joints. This rapid set holds the groove cross-section constant, not allowing the fresh concrete to flow and compress the sealant to close the joint. The gun head is flushed with a solvent after each use. He believed the compound could be altered to provide a "pot life" of up to 3 minutes. Any usage requiring a longer "pot life" would necessitate the use of a different compound.

Mr. Sutton believed the cost of the joint would approach $0.25 per lineal foot installed ($0.20 material, $0.05 to open and finish joint). The useful life of the joint would be approximately 50 years, with exposure above water level to ultraviolet rays causing the most aging. He felt the compound would be compatible with most other construction materials.
Guest speaker at this meeting was Mr. Enos Ryland who lectured on construction practices in canal linings.

Prior to 1947, concrete linings were mainly of the reinforced type, but major canals such as the Friant-Kern, Coachella, and Delta-Mendota began the era of unreinforced linings. The Friant-Kern was the first to receive an unreinforced lining; a part of one reach was installed without control grooves. It was immediately apparent that this type of lining would crack extensively. Grooves were then introduced to control the expected cracking. These first grooves were installed under a change order; therefore, were very expensive. Later reaches were built with the grooves included under the specifications and prices were much lower.

The Friant-Kern Canal had 1-1/4 to 1 side slopes and hand formed grooves. After the fresh concrete was found to creep and close the joints, the contractor tried a method of inserting lath to keep the grooves open. The contractor also tried to cut the grooves in green concrete with a diamond saw but random cracking was found to have already occurred. The saw tended to pull aggregate out if the concrete was too green at the time of sawing. Sawing was therefore discontinued.

The first mastic joint fillers used were two components with a thinner. Some contractors used too much thinner to facilitate placement and this resulted in the mastic flowing down the grooves and puddling on the canal invert. Control of the mastic viscosity was very difficult even with exact mixing methods. When exposed to sun and weather even properly mixed mastic hardened and cracked, but when protected by water, the mastic appeared to function properly.

A private firm attempted to interest the Bureau and contractor in the development of equipment to insert the mastic within the lining thickness during placing of the fresh concrete. The method was used only on invert paving but was soon discarded. As no better mastic was available, grooves as such were relegated to crack control only and their width was made insufficient for placement of a sealant. In 1950-1951, the use of joint filler was abandoned. It was intended that the cracks would be filled later if seepage control was necessary. As a result, many grooves and cracks have never been filled.

In Mr. Ryland's experience he has observed that subsoil conditions appear to determine the spacing of control grooves. On sandy pervious soils, the slabs appear to travel with stress, therefore cracking is at greater average spacing but these cracks are large. On tight firm subsoils, the lining generally tends to crack at 12- to 15-foot average intervals on large canals. On smaller canals with thinner linings the spacing is somewhat closer.
On a short reach of the Friant-Kern Canal the lining was placed directly on a catalytically blown asphalt membrane which was very slippery. A portion of this section of lining was placed with no grooves. There were instances where crack spacing exceeded 100 feet. In those cases, crack widths were approximately five-eighths inch.

Mr. Ryland presented a history of the use of "Constop" as a crack controller and sealer on the San Luis Canal. He believes this is a proper material and method to use in relatively thick linings (3 to 3-1/2 inches or thicker). In thinner linings there will not be adequate room to install "Constop" in both directions. Therefore, "Constop" should possibly be used in longitudinal joints and polysulfide filled grooves in the transverse joints.

Originally, polysulfide compounds did not readily adhere to wet or cold concrete; they were therefore of no use for winter repair of cracks in northern climates. Groove depths of one-third-slab thickness, as presently specified, show good performance. Mr. Ryland believes that most of the cracking which deviates from the line of the groove occurs where the slab is noticeably thicker than specified. Also, that a 15-foot groove spacing is adequate in general, but is possibly too great for use on a firm subgrade and in smaller canals.

At times up to 20 concrete finishers are used to obtain the finished and grooved concrete on a large canal. Mechanical finishing, grooving and filling would reduce overall labor cost considerably. Research should be aimed toward placing all operations in the construction train and accomplishing all work in a single pass of the finishing and grooving equipment.

MINUTES OF THE TWELFTH MEETING
January 18, 1967

Guest speakers were Messrs. Richard Wilson and John Walker who showed slides and discussed the O&M aspects of sealing concrete canal linings. They emphasized the need for a low cost and easy to use crack filling material with a reasonably long life. The work being done on one project or district is not generally known by others. For example, one district may not be aware of the type sealer used by another. Mr. Wilson indicated that most canals turned over to O&M in the past were not (and have not been) sealed. No real attempt has been made by many districts to keep up with the sealing or resealing unless seepage is causing damage to the canal and adjacent land or the loss of water is important. Sealing cracks and joints in concrete lining usually represents a minor part of the O&M budget and work program.

One method used for sealing concrete linings was illustrated by a photographic slide of the New York Canal. This relatively wide shallow canal
has had part of its concrete lined invert paved with asphalt. Some sections with relatively high velocities (above 8 fps) have required repairs as the asphalt has been eroded and torn off the bottom.

The Kennewick Canal was installed without joint filler. Sealing of all joints has been recommended to reduce loss of water and prevent canal failure. In several reaches of canal in the Columbia River Basin Project, fine subgrade material has been piped into rocky substrata causing cavities below the lining requiring extensive repairs.

O&M's experience shows that more cracks can appear along the inside of curves (as opposed to the outside). High-water tables along a canal can promote extensive cracking and lining. Considerably less compression spalling of the concrete appears where joint spacing is closer, such as 6 feet or so.

Slides of the Heart Mountain Canal, Shoshone Project, showed effects of canal leakage on underlying bentonite seams. Extreme buckling of the lining occurred. Leakage through cracks, in turn, allows more moisture to expand the bentonite, compounding the buckling. Slides of the Delta-Mendota Canal showed attempts to halt lining buckling due to an expansive clay foundation. Temporary repairs were effected with bags of soil-cement placed on the buckled concrete panels.

Slides of the Putah South Canal lined section showed application of a "Chevron" sealant in an attempt to diminish leakage through the subgrade. This method appeared satisfactory for a time, but was not a permanent solution.

When installing weep valves, it is necessary to consider water velocity as some rubber flap valves on the Esquatzel Canal were ripped off by high velocities.

Compatibility of new sealant materials with existing sealers is very important to avoid ruining satisfactory in-place sealers. Polysulfide rubber compounds have been used by some irrigation districts, but not extensively. Polyurethane materials are now coming on the market. Prestite 67, which is a one-component rubberized mastic, appears to be the sealant most generally used. The individual irrigation district manager makes the decision as to the type of sealant used on the district canals.

MINUTES OF THE THIRTEENTH, FIFTEENTH, AND SUBSEQUENT MEETINGS

No guest speaker was obtained for these meetings, as they were devoted to general discussions of the canal sealant problem and to the preparation of the final report.
MINUTES OF THE FOURTEENTH MEETING
February 8, 1967

Guest speaker at this meeting was Mr. E. C. Higginson who discussed the shrinkage and expansive characteristics of concrete. He said concrete in some ways is analogous to mud which cracks and curls when it dries. The amount of concrete shrinkage is due almost entirely to the amount of water and the type of aggregate used. In South Africa, some aggregates containing graywacke were found to have approximately three times the shrinkage characteristics of the normal aggregates we use in this country.

Portland cement does not contribute as much to shrinkage of concrete as the water content does. The major reasons for concrete volume change are: (1) drying shrinkage, (2) thermal changes, (3) reactivity (from chemically reactive aggregates), (4) autogenous volume change, (5) change due to temporary outside stress, and (6) flow and creep from longtime outside load.

Concrete is similar to ceramic ware. It is susceptible to thermal shock, even with small temperature changes.

At present, the cement manufacturers are conducting research to find an expansive type of cement. In 1965, approximately 300,000 barrels of this type were produced in the United States. This cement uses a chemical reaction to produce expansion rather than shrinkage upon setting. Trouble has been experienced in controlling the exact amount of this expansion to precisely balance the amount of shrinkage that the cement would otherwise be subjected to. Great use of this cement is envisioned in producing prestressed members if adequate control can be maintained. It is still considered to be an experimental cement.

The best way to produce shrinkless concrete at present is to place the concrete cold and keep it moist and just above freezing until cured. California State Department of Water Resources has been convinced that concrete mixes containing ice are economically feasible.

Mr. George Birch stated he believes the present system of grooving and filling the grooves in concrete canal linings is costing approximately 3 to 4 percent of the total lining costs. This would then be a maximum cost of crack prevention methods which could be adopted in lieu of grooving.

Mr. Higginson feels that at present there is no sure way of preventing cracking of concrete; therefore, we will have to adjust our designs accordingly. It is considered good practice to produce cracks where desired and then fill them. By so doing, thermal, wetting and drying, and stress cracks do not occur later where not wanted. To reduce random cracking, canal lining aggregate is at present screened to
three sizes rather than the two sizes used on other structures. More sand is used, and the mix design has been adapted to fit the present mechanical paving operations. Mr. Higginson believes concrete research should center on cement, which is manufactured, rather than on aggregate, found naturally, so that better control of the final product can be maintained.

Despite outward appearance, more control is apparently exercised in Bureau concrete manufacturing than in ordinary steel manufacturing as tests of concrete in compression are more uniform than tests of reinforcing steel in tension.

One of the greatest needs of the moment is to conduct research for an improved portland cement. The needed work is not being done by the cement companies.