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Classification of Construction Problems in Rigid Highway Pavements

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Abstract: Problems can be expected during construction of rigid pavements, since this process is sophisticated, and involves many activities like concrete placing, spreading, compacting, finishing, texturing, curing, protecting, jointing, testing, and other sub-activities. In addition, this process is performed over large areas, outdoors,and under miscellaneous conditions. Classification of these problems can be very helpful in control, minimize, and prevent them. This paper presents classification of construction problems in rigid highway pavements depending on their forms, appearances, locations, stages of occurrence, conditions, and any other common features among them. The problems, their description, probable causes, instantaneous solutions, preventive solutions are documented depending on written sources in the domain of rigid pavements construction.

Key words: Construction problems, rigid pavements, causes, solutions.

INTRODUCTION

Pavement construction is a team effort and success in construction comes by applying this effort intelligently at a price for a stated time. In other words successful construction meets the planning and design objectives, within budget and time constraints (Ralph Hass, 1987). There was a concentrated search by highway agencies for methods of reducing construction costs, upgrading pavement quality and reducing high annual maintenance budgets (ACI 325.12R-02, 2002). To improve their competitive position, highway contractors are attempting to improve their operational efficiency that leads to an increase in production capacities, and to reduce capital equipment investments as well as reducing overhead expenses (Transportation Research Board (TRB), 1975). However, people who have performed construction-engineering services know that there are always problems during construction, which cannot anticipated during design (ACI 224.1R-07, 2007). Adverse weather conditions, bad site preparation, equipment breakdown, difficulty in finding experienced and skilled staff and badly produced concrete are few examples (Ken Newman, 1986; John P. Zaniewski, 1987).These problems range from annoying or worrying (as with early-age plastic shrinkage cracking) to the financially catastrophic, where major disruption may result in costly repairs (Ken Newman, 1986). Many factors that affect the desired quality of the constructed rigid pavements road, eventually, govern the satisfactory performance of rigid pavements. The most important contributing factors are well production of concrete that complies with specification, well preparation of subgrade soil and well concreting operations at site (ACI 318M-08, 2008).

In general, and to ensure that a pavement of desired quality, concerning smoothness of ride and durability requires considerable care and expertise at all stages of construction from subgrade preparation to final texturing and curing (Stock, 1988; ACI 311.4R-05, 2005). Good practices and controls during the construction operations of rigid pavement slab, which the present paper concerns with, including careful inspection and supervision, are essential to the performance of the pavement (Lewis, 1986).

Attaining quality includes all that influences the effectiveness of sufficient inspection and testing to insure that specified results are attained at all stages of construction. It also includes strong, clear pavement specification which clearly spell out requirements, standard, limits and certain equipment and methods which do much themselves to insure quality if they are followed. Moreover, it includes good training, as well as able supervision for the inspection and testing to be, at least, able to know the requirements (Lewis, 1986). Holding pre-bid and pre-construction meetings, attended by responsible representative of the owner and contractor, architect and engineer, inspection and testing people and concrete suppliers, are considered as an important early move in that direction. This mutual understanding for both specifications and potential problems are promoted, and acquaintance and communication are established, such meeting during construction stage can

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also helpful (Lewis, 1986; ACI 302.1R-04, 2004).

2. Factors Effecting Construction:

In fact, the same materials, which are, cement, sand, aggregate, water and reinforcement, are used to prepare the mix which is used in construction of rigid pavement. The obtained slab sometimes behaves and looks to be good, and other times the slab has a bad behaviour and appearance. There is of course no simple answer to explain these differences in the obtained products, but major contributing factors that can be summarized as follows:

1. Over the years, the engineer and contractor have had to deal with major changes in methods of construction. There is ever increasing difficulty to find staff with the necessary skill and experience which able to carry out concreting operations on site. Computerized design methods move the engineer even further from practical realities. It is still easier to assess and test materials products than its construction practices (Ken Newman, 1986).
2. Most of concrete today is manufactured off the job site and away from the direct control of the resident engineer, (which is a ready mixed concrete). This has produced another contractual and communications interface where misunderstandings and mistakes may occur (ACI 304R-00, 2000; ACI 302.1R-04, 2005).
3. The aspect of environmental protection and energy saving have led greater planning restriction on cement and aggregate material processing and press to use by-products such as pulverized fuel ash, ground granulated slag and silica fume, often of unknown and variable quality. Again, the lack of experience, proper understanding, and control over the use of these materials can lead to problems (Ken Newman, 1986).
4. Adverse climatic conditions may influence the construction operation and then affect the quality desired (Republic of Iraq, 1983; Standard, 2002).
5. Bad preparation and scheduling at the site can cause interruption among the construction operation stages (Ken Newman, 1986).

3. Domain of the Study:

Many problems can occur during construction of rigid pavements such as preparation of under-layers, materials selection, concrete producing, hauling, placing, compacting, finishing, and curing.

This paper concerns with problems that occur between placing time and the time of opening the road to the traffic. This involves concrete placing, spreading, compacting, finishing, texturing, jointing, curing, protecting, testing, and final checking. Methods of rigid pavement construction like semi-manual construction-methods to fully mechanized construction, methods by fix form paving, and slip form paving methods are involved in this paper.

This paper does not involve diagnosing the problems associated with production and hauling of concrete to the site, as it considers that the concrete is to be supplied by ready mix plants that are provided with all information needed about the quality of the product.

This paper does not involve diagnosing the problems associated with construction and preparation of the roadbed, as the study considers that there is a ready roadbed previously constructed but that does not prevent testing the regularity of this ready roadbed due to the importance of surface regularity on the performance of the concrete road.

4. Classification of the Problems:

Through the extensive review of the specialized references and repeated analysis, the domain problems are classified depending on their forms, locations, effects, and other common features in order to be diagnosed by the inspectors visibly or depending on tests and measurements results. In addition, the problems description, likely causes and solutions are stated.

Domain problems are classified into categories according to the common features and conditions, each category includes a number of problems. These categories and problems are stated below:

A. Concreting under Bad Conditions:

These are problems restricting the construction process like bad weather, machine stop, and discontinuity of concrete feeding.

B. Bleeding:

Appearance of water at the surface of the plastic placed concrete at any stage of construction.

C. Cracking:

These are cracks which appear at the concrete surface during plastic stage (when the concrete still fresh) or after hardening of concrete (during curing process).

D. Joint Construction Problems:

These are problems related to the formation of the joint groove or to the sealing of the joint.

E. Surface Irregularity:

Presence of spots of high and low level differs from the specified.

F. Dusting of Pavement Surface:

Development of a fine, powdered material that easily rubs off the surface of hardened concrete.

G. Scaling of Pavement Surface:

Hardened pavement surface scaling can lead to severe pavement abrasion.

H. Honeycomb Forms:

Irregular air voids appears at the extracted testing cores or at the side faces of the slab after removing of the forms.

I. Tests Results Problems:

These problems can be diagnosed during the final inspection phase depending on field or laboratory tests results and measurements.

Interaction among the problems, their descriptions, causes, and solutions is expected due to their common features and unity of the subject, but without any conflict among them.

Figure (1)illustrates the diagram of domain problems classification.

Description, likely causes, and possible solutions are explained in the following articles.

A. Concreting Under Bad Conditions:

Bad conditions during pavement construction process can be expected, since this operation is performed outside and on wide area of different weather, topography, environment, facilities, resources, and other features. Table (1) demonstrates the probable causes of these problems. Hot weather placement generally has conditions that are more problematic especially since ambient air temperature above 30^{o}C is critical (Frank McCullough, 1999; ACI 305.1-06, 2007). Cold weather can stop the concreting when the temperature is 5^{o}C and fall since such weather has harmful effects on the concrete (ACI 306.1-90, 2002). The concrete temperature shall be measured before placing in accordance with ASTM C1064 or AASHTO T309.

The problems can be explained in the following articles:

A1. Rapid Slump Loss:

Rapid decrease in the concrete fluidity that leads to rip or tear slab surface during finishing (ACI 302.1R-04, 2004; ACI 121R-04, 2004).

•Instantaneous Solutions (ACI 325.12R-02, 2002.; ACI 305R-99, 1999):

1. Add small quantity of extra water to the concrete in order to substitute the lost water due to evaporation during concrete hauling and placing.
2. Sprinkle the slab surface with minimum quantity of water from a fine jet in order to aid the finishing process in the extreme cases.

• Preventive Solutions (ACI 224.1R-07, 2007; Walter Price, 1982):

1. Supply mixtures of highest practical slump.
2. Place and finish concrete during the coldest interval of the day as soon as delivered.
3. Shade forms, reinforcement and subgrade or cool them with water prior to concrete placing.
4. Reduce wind velocity using windbreaks.
5. Protect concrete with temporary coverings during any delay between concreting operations.
6. Increase humidity at the surface by fog spraying during concreting and until curing starts.

A2. Concrete Setting Rate Increases Rapidly:

Rapid concrete stiffening leads to difficulty in concrete spreading (ACI 305.1-06, 2007).

• Instantaneous Solutions (ACI 305.1-06, 2007; ACI 305R-99, 1999):

1. Complete the concreting operation as soon as possible to avoid final setting of the concrete before finishing by increasing the labours and machinery efforts.
2. Instruct the concrete plant operators to reduce the delivered concrete to ensure stable proportioning between the delivered and placed concrete.

• Preventive Solutions:

Adopt the steps stated in article *A1* and use retarders of concrete hardening.

A3. Raining During Construction:

This problem may take place during any stage of the construction operation. Rainwater has very harmful effects on concrete, since it resolves concrete structure and eliminates its strength (Innovative Pavement Research Foundation, 2005)

***• Instantaneous Solutions (Innovative Pavement Research Foundation, 2005, ACI 330R-01, 2001)*:**

1. Stop the construction operation.
2. Inform the concrete plant operators to stop concrete feeding.
3. Perform construction joint for the last performed part.
4. Protect the performed parts from rainwater by covering them by suitable covers. Care shall be taken to avoid distorting the concrete surface by water or covers.
5. Resume the construction operation after rain stopping or if protection arrangements (like temporary shades) are implemented to protect the concrete from the rainwater entirely.
6. Remove and reconstruct the defected parts of the pavement.

• Preventive Solutions (Innovative Pavement Research Foundation, 2005):

1. Adopt correct and accurate weather information.
2. Adopt high-level management plan in addition to plan for emergency cases.
3. Employ experienced staff.

A4. Concreting During Cold Weather:

This problem can appear in cold areas when the temperature is 5^{o}C and falling. Low temperatures can affect risky damages in concrete structure due to freezing action (ACI 306.1-90, 2002; Flaharty, 1988).

• Instantaneous Solutions (ACI 306.1-90, 2002; Flaharty, 1988; ACI 212.3R-04, 2004):

1. In case of sudden decrease in temperature, adopt action of article *A3*.
2. If the concrete must be placed in cold weather the following action can be implemented:

a) Heat the aggregate and water to moderate temperatures to make the temperature of the concrete between 10^{o}C and 25^{o}C prior to placing.
b) Produce concrete using rapid-hardening cement.
c) Add calcium chloride to the mixture to accelerate the hydration process that produces large amount of heat and increase concrete temperature.

• Preventive Solutions (Innovative Pavement Research Foundation, 2005; ACI 212.3R-04, 2004):

Adopt the steps of article *A3* and use rapid-hardening Portland cement and calcium chloride to the mixture to accelerate the hydration process that produces large amount of heat and increase concrete temperature.

A5. Concreting During Dusty Weather:

Contamination of concrete with dust due to dusty weather that reduces strength and durability of concrete.

• Instantaneous Solutions (ACI 330R-01, 2001; ACI 302.1R-04, 2005):

1. In case of slight dust, the problem can be neglected.
2. In case of considerable dust that can cause significant contamination in concrete, adopt the first five steps explained in article *A3* and take additional samples from the contaminated parts to ensure their compliance

to the requirements of strength and durability else, these parts shall be removed and reconstructed.

• ***Preventive Solutions:***

Adopt same steps as in article*A3*.

A6. Paver Failure During Construction:

This problem may take place during concrete placing that can interrupt the construction process (ACI 304R-00, 2000; ACI 330R-01, 2001).

• ***Instantaneous Solutions (ACI 304R-00, 2000; ACI 330R-01, 2001):***

1. Stop the construction operation.
2. Inform the concrete plant operators to stop feeding of the concrete.
3. Perform construction joint for the last performed part.
4. Resume the construction operation when the machine is re-operated and its efficiency is ensured, or when new machine is provided.

• ***Preventive Solutions (Standard Specification for Urban Infrastructure, 2002; ACI 121R-04, 2004):***

1. Adopt periodic maintenance to construction machines and prepare detailed report for each one.
2. Adopt high-level management plan in addition to plan for emergency cases.
3. Employ experienced staff.

A7. Discontinuity of Concrete Feeding During Construction:

Irregular, interrupted, or discontinuous concrete delivery to the site can interrupt construction process and lead to other problems (ACI 302.1R-04, 2004; ACI 302.1R-04, 2005).

• ***Instantaneous Solutions (ACI 304R-00, 2000; ACI 330R-01, 2001):***

1. Stop the construction operation.
2. Perform construction joint for the last performed part.
3. Contact the plant operators to solve the problem.
4. Resume the construction operation when uniform concrete feeding is provided.

• ***Preventive Solutions (ACI 304R-00, 2000; Standard Specification for Urban Infrastructure, 2002):***

1. Maintainthe concrete plant and trucksperiodically and prepare detailed report for each one.
2. Provide the site with concrete from the nearest plants.
3. Deposit sufficient materials at the plant site.
4. Provide good communication among site, plant, and trucks operators.
5. Adopt high-level management plan in addition toa plan for emergency cases.
6. Employ experienced staff.

A8. Contamination of Concrete by Sub-base Material:

Sub-base material can contaminate the concrete during placing, compacting, or any other handling step (ACI 302.1R-04, 2004; ACI 302.1R-04, 2005).

• ***Instantaneous Solutions:***

Remove the contaminated parts and substitute with new concrete (ACI 311.4R-05, 2005).

• ***Preventive Solutions (ACI 121R-04, 2004; ACI 309R-05, 2005):***

1. Ensure correct preparation for the sub-base layer prior to concreting.
2. Cover the sub-base layer with membranes.
3. Employ experienced staff with proper tools (avoid garden tools).
4. Ensure correct vibration process and avoid immersing vibrators vertically or deeply.

B. Bleeding:

Appearance of water at the surface of pavement slab at any stage of construction that bringing cement and aggregate fines to the surface (ACI 116R-00, 2000; Ravindrarajah, 2003).

C. Causes (Stock, 1988; Ravindrarajah, 2003):

Continuous consolidation of concrete by sedimentation of its constituents and this feature is aggravated due to the following factors:

1. Slow setting of concrete due to low air temperature or due to using of setting retarders.
2. Using low cohesive mixtures.
3. Over vibration of concrete mixture.
4. Excessive floating or troweling during finishing stage.

• Instantaneous Solutions (ACI 304R-00, 2000; Ravindrarajah, 2003):

1. Remove any accumulated water by blotting with mats, draining, or by pulling off with hose loop.
2. Avoid dusting surface with neat cement or mixture of sand-cement to dry it prior to finishing.

• Preventive Solutions (ACI 318M-08, 2008; ACI 212.4R-04, 2004):

1. Provide mixtures of lowest practical slump that can properly be compacted.
2. Protect the concrete from harmful weather conditions.
3. Avoid excessive vibrating.
4. Minimize floating and trowelling of the surface as possible.
5. Delay each finishing step as long as possible to remove any accumulated water before any floating passage.

C. Cracking:

Crack is a complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing (ACI 116R-00, 2000). Table (2) abstracts the causes of the cracking. This category is divided into two groups: cracking of plastic concrete and cracking of hardened concrete. Each group involves number of exclusive problems as explained below:

C1. Cracking of Plastic Concrete:

These cracks occur at the surface of fresh concrete during the interval after concrete placing (when it is possible to be re-moulded) and before concrete hardening (ACI 116R-00, 2000). This interval may ranges from 1 hour to 12 hours depending on air temperature,water content in mixture,and using of accelerators or retarders in mixture (Walter, 1982).This type of cracking includes the following problems.

C1.a. Diagonal Shallow Cracks:

These cracks are usually diagonal in direction, in accordance with the bay border, and do not reach the slab edges. They are quite shallow and soon diminish in width occur in the interval interposed compaction and application of the curing compound at the time water sheen disappears from the surface of concrete, these cracks arenot often detrimental, except for the appearance (Stock, 1988; ACI 116R-00, 2000).

• Instantaneous Solutions (Stock, 1988; Flaharty, 1988):

1. Re-vibrate the placed concrete to remove these cracks. This action involves disrupting the finished concrete and risking alignment problems, so such action shall be performed carefullyand before final setting of the concrete.
2. For small paving width, it is possible to treat the cracks manually by troweling but quickly and without overworking tostart curing early.
3. If the pavement surface hardened, treat the cracks by applying of cement mortar carefully to improve the surface appearance and to close them.

• Preventive Solutions (ACI 224.1R-07, 2007; Walter 1982):

1. Use water reducing agents and air entraining agents in the mixture.
2. Reduce the evaporation rate from the surface in hot weather by the following actions:

a) Minimize concrete temperature by cooling side forms, reinforcement and subgrade by shading or spraying them with water, placing concrete during coldest interval of the day, and protecting concrete with covers during any delay among construction stages.
b) Construct windbreaks to reduce wind velocity.
c) Increase humidity of ambient by fog spraying during finishing until curing starting.
d) Start curing process as soon as possibleby applying curing compound.

C1.b.Craze Cracks:

Craze crack is a pattern of fine cracks that do not penetrate much below the surface and are usually a cosmetic problem only. They are barely visible except when the concrete is drying after the surface has been wet. These cracks sometimes appear in a hexagonal pattern on the surface of concrete after finishing at an early age (ACI 302.1R-04, 2004; Walter, 1982).

• ***Instantaneous Solutions:***

Adopt same actions as in article *(C1.a).*

• ***Preventive Solutions (ACI 302.1R-04, 2004; Ravindrarajah, 2003):***

1. Reduce the bleeding by adjusting the components of the provided mixtures, using air-entraining agents,or adding water reducing agents.
2. Minimise the floating and troweling operations as possible.
3. Avoid application of cement powder on concrete surface to dry it during finishing.
4. Remove the accumulated water between finishing operations by blotting with mats, draining, or pulling off with loop of hose, so as the surface can lose its water sheen before performing the next finishing operation.
5. Perform early curing by no more than 10 minutes after finishing.

C2. Cracking of Hardened Concrete:

Hardened concrete shrinks by about (0.05%) of its length when it dries. It shrinks more if concrete when mixed contains large amount of water. Moreover, concrete has a coefficient of thermal expansion and contraction of about(8-12 $*10^{-6}/^{o}C$) (Walter, 1982; Saloua El EuchKhay, 2010). Restraint of pavement can cause cracking in two patterns that are cracks within slab and cracks near joints.

Cracks Within the Slab:

This pattern involves the following problems:

C2.a. Transverse and Oblique Cracks:

These cracks appear at transverse, oblique, or random direction of the hardened concrete highway panels (ACI 224.1R-07, 2007; Army Corps of Engineers, 2001).

• ***Instantaneous Solutions (Raymond Sharp, 1970; Peter L.Critcheli, 1968):***

1. Hair cracks (less than 0.5 mm wide) do not need attention particularly in reinforced slabs, since they do not admit water.
2. Wider cracks up to 3mm should be widened and sealed in accordance with the following procedure:

a) Reface the cracks sidewalls with diamond saw blades to provide an adequate width and depth to enable the admission of sealing compound, a groove of (25 mm depth × 12 mm wide) is acceptable.
b) Clean the newly sawed sidewalls with water followed by drying and sand blasting.
c) Install a caulking strip of compressible material to provide the correct depth for the sealing cavity.
d) Prime the groove, after drying, with prime coat and seal with high quality sealant.

3. When the pavement slab is badly cracked (with cracks wider than 3 mm), it is cheaper and more satisfactory to replace whole or part of the slab by *Full Depth Repair Procedure*.

• ***Preventive Solutions:***

1. Prevent dowel restraint (Stock, 1988; ACI 224.3R-95, 2001).
2. Use mixtures of minimum practical amount of water (ACI 209.1R-05, July 2005).
3. Form the joint grooves by cut sawing procedure as soon as possible (ACI 325.12R-02, 2002).
4. Ensure enough concrete maturity before sawing else spalling of aggregate particles may occur during sawing (ACI 325.12R-02, 2002, Stock, 1988).
5. Use low alkali cement where aggregate is reactive (ACI 221.1R-98, 1998).
6. Ensure proper curing and protect concrete slab from harmful weather conditions (Republic of Iraq, 1983)
7. Perform contraction joints at spacing of about (4-6 m) intervals in unreinforced concrete to control the location of the cracks (ACI 325.12R-02, 2002; ACI 224.3R-95, 2001).
8. Check the regularity of the sub-base prior to concreting by rolling straight edge (ACI 325.12R-02,2002).
9. Perform adequate concrete compaction efforts to extrude the maximum possible amount of entrapped air

(ACI 309R-05, 2005; ACI 309.1R-93, 2005).

10. Avoid overworking of the surface during finishing stage to possible minimum to prevent rising of wet soupy material which cause high drying shrinkage (ACI 302.1R-04, 2004; ACI 309R-05, 2005].

C2.b Longitudinal Cracks:

Cracks parallel to the centreline of pavement. Such cracks development in the pavement slab is not expected but if this happened, it is an indication that something is missing (ACI 302.1R-04, 2005; ACI 116R-00, 2000).

• Instantaneous Solutions (ACI 224.1R-07, 2007; ACJ 330R-01, 2001; Raymond Sharp, 1970):

1. Hair cracks (less than 0.5 mm) do not require attention, as they do not admit water particularly in rein forced slabs.
2. Repair hair cracks in unreinforced slab and medium cracks (up to 3 mm) in slabs of both types by means of *Stitched Crack Repair Procedure*.
3. Wider cracks greater than (3mm) for both types should be remedied by *Full Depth Repair Procedure* or by means of replacement of the failed slab according to the *Procedure of Failed Slab Replacement.*

• Preventive Solutions (ACI 224.1R-07, 2007; Stock, 1988; Innovative Pavement Research Foundation, 2005):

1. Minimize water content in the supplied mixturesas possible.
2. Ensure regularity of the sub-base before concreting by rolling a straight edge to remove any irregularities that may exist and restricts the free movement of the slab.
3. Install bottom crack inducers at the longitudinal joints.
4. Start cut sawing as soon as possible.
5. Cure and protect the concrete from harmful weather conditions.
6. Avoid overworking of the surface to prevent rising of wet soupy material which has high drying shrinkage properties.
7. Reduce the slab width.

C2.c.Corner Cracks (D-cracks):

These cracks are diagonal in direction, forming a triangle with the longitudinal edge or joint and transverse joint, and they continue through the full depth of pavement slab (ACI 325.12R-02, 2002; ACI 224.1R-07, 2007).

• Instantaneous Solutions:

For sever cases or long corner cracks, *Full Depth Repair Procedure* can be implemented otherwise *Full Depth Repair with Asphalt Concrete* can be adopted.

• Preventive Solutions (Critcheli, 1968; ACI 224.3R-95, 2001):

1. Prevent dowel restraint.
2. Clean the grooves before sealing by washing them with jet of water immediately after the passage of concrete saw and then follow by high-pressure jet of compressed air or by blasting with sand or grit to dry it and to be free from dust, concrete fragments, or other deposited materials.

Cracks Near or at the Joints:

This pattern involves the following problems:

C2.d. Transverse and Diagonal Cracks at Transverse Joints:

These cracks are either at or near the joint by (30-45 cm) from the joint and along its length.

• Instantaneous Solutions:

Apply *Full Depth Repair Procedure*.

• Preventive Solution (Stock, 1988; Army Corps of Engineers, 2001):

1. Prevent dowel restraint.
2. Avoid the discontinuity of the joints by adopting the following steps:

a) Ensure that the grooves extend across the bays from form to form in case of transverse joint; continue in case of longitudinal joints, and groove depth touch top of filler board.
b) Ensure that the joint filler sufficiently robust to withstand the deposition and compaction of concrete without tending to fracture buckle or fray. This can be achieved by using a rigid assembly to locate the joint filler and the dowels in their positions firmly.
c) Place filler boards with no gaps below them, among the successive boards in the same line, or between the boards and the former or previously placed concrete.
d) Mark the position of each transverse joint groove on the plastic concrete accurately.

3. Compact the concrete around the wet formed grooves carefully to avoid bad influence on the longitudinal profile of pavement across joint.
4. Start sawcutting as soon as possible.

C2.e. Longitudinal Cracks at Longitudinal Joints:

These cracks are either at or near the longitudinal joints (i.e. within the length of dowels or adjacent to them).

• ***Instantaneous Solutions:***

Apply *Full Depth Repair Procedure*.

• ***Preventive Solutions:***

Fix bottom crack inducer firmly and locate the position of the longitudinal joint groove accurately above it (Stock, 1988; Army Corps of Engineers, 2001).

C2.f. Cracks at the Intersection of Joints (Critcheli, 1968):

Suchcracks can take place at the points of intersection between the longitudinal and transverse joints as shown in figure (2).

• ***Instantaneous Solutions:***

*Adopt Full Depth Repair with Asphalt Concrete*as follows:

1. Remove the damaged area.
2. Level the sub-base if required and prime it.
3. Apply tack coat to the sides of the slab.
4. Place, in layers not exceeding 100mm each in thickness, dense-graded asphalt concrete.
5. Compact the placed asphalt mixture with vibrating plate compactor.
6. Finish the surface to the correct level according to the surrounding pavement.

• ***Preventive Solutions:***

1. Ensure that the groove extend across the bays from form to form in case of transverse joints and continuous in case of longitudinal joint.
2. If the cracks have not already developed, apply cut sawing procedure on the remaining part of the groove (which is not yet sawn) before preparation of the joints for sealing.

D. Joint Construction Problems:

Joints construction is the most important aspect in rigid pavement construction that is why it is important to overcome all the probable problems associated with their construction (Stock, 1988).These problems can appear during the formations of the groove by forming strip when the concrete still plastic, by sawcutting after setting of the concrete or during joint sealing.

D1. Disruption of the Compacted Concrete Around the Wet Formed Groove:

Humps of concrete along the sides of the formed groove that formed by strip formers when the concrete still plastic (ACI 224.3R-95, 2001).

Causes:

Improper grooving method, by unskilled or carless staff, causes the disruption of the compacted concrete around the formed grooves by the insertion of a vibrating blade in concrete to form the groove and then vibrating the plastic former in the formed groove or by a direct insertion of a straight edge in concrete, and then inserting plastic former (Transport and Road Research Laboratory, 1975).

• Instantaneous Solutions:

Distribute the concrete humps by using a straight edge of 10 feet length attached to the end of a long flexible rod that is dragged transversely across the surface of the slab. This straight edge should has a rebate at its centre allowing to bridge the joint to avoid displacement of the plastic formers and to ensure that mortar is not floated over these formers. Any floated material shall be immediately removed after passage of this straight edge and the concrete shall not be overworked to prevent any irregularity in the profile of the pavement across the joint. This activity shall be performed prior to the final setting of the concrete (Critcheli, 1968)

• Preventive Solutions (Stock, 1988):

1. Use mixtures of maximum practical slump
2. Use mixtures with minimum possible (maximum aggregate size).
3. Employ skilled carful staff and adopt correct method of forming accurately.

D2. Dislodgement of Aggregate Particles along Sawn Groove:

Unacceptable ravelled edges along the sides of the sawn groove by spalling of aggregate (*Stock, 1988,* ACI 330.1-03, 2003).

Causes (Stock, 1988;, ACI 330.1-03, 2003):

1. Early sawing time that is a function of concrete maturity especially when concrete contains flint gravel or other hard gravel types, which require long time to bond with the paste of cement tightly.
2. Presence of relatively high percentage of entrapped air due to improper compaction.
3. Using of exhausted blades or sawing discs to cut the grooves.

• Instantaneous Solutions:

1. Stop sawcutting process until attaining enough concrete strength and then resume the process using high quality blades or discs.
2. Adopt *Spall Repair Procedure* to repair any spalled edges.

• Preventive Solutions (Stock, 1988; ACI 224.3R-95, 2001):

1. Perform cut sawing activity as soon as possible.
2. Use straight qualified blade and select the correct type according to the type of aggregate used, the instructions of the manufacturer,and the age at which cutting is performed.
3. Ensure proper compaction effort.

D3. Displacement or Tilting of Joint Former:

The temporary or permanent formers tilted from their correct positions (ACI 224.3R-95, 2001).

Causes (Stock, 1988; ACI 504R-90, 1997):

1. Interruption may occur between insertion of longitudinal and transverse forming strips.
2. Interruption of the formers by finishing tools especially if the formers are not inserted in the concrete to the correct depth.

• Instantaneous Solutions:

1. If this problem is noted before concrete setting, remove the formers, refill the groove with concrete, rework the surrounded area, and reform the joint correctly.
2. If this problem is noted after concrete hardening, *Spall Repair Procedure* can be adopted.

• Preventive Solutions (Stock, 1988):

1. Avoid any interruption during former insertion.

2. Insert the groove formers to a depth of (3-6) mm below the slab surface. Considerable amount of handwork is required to clean the tops of formers after each passage of finishing tools.

D4. Improper Sealing of the Joint:

Incomplete or incorrect sealing of thejoint results in water passage through the joint (ACI 325.12R-02, 2002; ACI 224.3R-95, 2001).

Causes (Critcheli, 1968; ACI 224.3R-95, 2001):

1. Insufficient adhesion between the groove and sealant.
2. Fracture of the sealing compound (brittle fracture).
3. Bubbling by small bubbles of air invariably trapped in the pores of the concrete.
4. Application of the sealing compound to a badly formed groove.

• Instantaneous Solutions (Raymond Sharp, 1970; ACI 224.3R-95, 2001; ACI 504R-90, 1997):

1. Remove the old sealant using a plough or rotating disc to remove lumps of the old compound with any lips that may exist at the top of the groove.
2. Repair any spalled edges according to *Spall Repair Procedure*.
3. Clean the sidewalls of the joint by rotating wire brush to be free from concrete fragments and any other deposited materials then wash the joint with jet of water and high-pressure jet of compressed air to blow out dust before sealing.
4. Prim the groove walls entirely and carefully and allow enough time for setting.
5. Apply sealing compound according to the instructions of the manufacturer.

• Preventive Solutions (Critcheli, 1968):

1. Use high quality sealing compounds and make the required laboratory test to ensure its validity for use under different weather conditions.
2. Apply the sealant onto a clean, dry, correctly primed, and non-defected groove.
3. Apply the sealant at its optimum temperature according to the instructions of manufacturer.

E. Surface Irregularity:

Presence of areas of higher or lower levels than the required by the specifications. These can be diagnosed by using 3m straight edge on pavement surface (ACI 302.1R-04, 2004; ACI 117-06, 2006).

Causes (ACI 302.1R-04, 2004; Transport and Road Research Laboratory, 1975):

1. Not uniform grading and workability of the supplied concrete.
2. Not uniform spreading of the concrete, which includes provision of differential surcharge.
3. Not uniform or insufficient compaction efforts applied to concrete.
4. Incorrect operation of the paving machines by unskilled staff.
5. Inadequate support of the forms in case of paving trains, or incorrect setting of guidelines in case of slip-form paving.
6. Incorrect joint forming.

• Instantaneous Solutions (Republic of Iraq, 1983; ACI 117-06, 2006; AASHTO, 1996):

Irregularitie sunder 3m straightedge of less than 3mm in longitudinal direction or 6mm in transverse direction can be neglected; otherwise, the following actions can be adopted:

1. Remove high areas by grindingit down in accordance with *Bump Cutting Procedure*.
2. Rectify low areas by cutting out to a depth no less than 20mm and replaced with concrete (thin bonded patching) in accordance with *Patching of Surfaces Procedure*.

• Preventive Solutions (TRB, 1975, Republic of Iraq, 1983; ACI 117-06, 2006):

1. Ensure uniformity of supplied mixes by frequent testing of work ability and strength at the site.
2. Establish and maintain spread surcharge when rail mounted euipment is employed.
3. Adjust paving euipment carefully and seuentially and maintain continuous check.
4. Use profilometer that gives an autographic record of the uality of the running surface.
5. Adjust the longitudinal speed of the vibrators based on their freuency to achieve enough uniform compaction effort.

6. Fix the side forms firmly in their positions.
7. Consider careful work when wet formed joint groovere-compaction is reuired along them.
8. Avoid over vibration as it influences the longitudinal profile of the pavement across the joint.

F. Pavement Surface Dusting:

Development of a fine, powdered material that easily rubs off the surface of hardened concrete (ACI 302.1R-04, 2004; ACI 116R-00, 2000).

Causes (ACI 302.1R-04, 2004; ACI 304R-00, 2000):

1. Floating and troweling concrete with bleed water on the surface mixes the excess water back into the surface, further reducing the strength and wear resistance at the surface.
2. Placing wet mixtures with poor finishing characteristics.
3. Insufficient cement in the mixture.
4. Excessive clay, dirt, and organic materials in the aggregate of the mixture.
5. Applying of cement powder on surface before finishing to dry it.
6. Applying water to the surface to facilitate finishing.
7. Inadeuate curing, allowing rapid drying of surface, especially in hot, dry, and windy weather.
8. Freezing of the surface.

• Instantaneous Solutions (ACI 302.1R-04, 2004; ACI 551R-01, 2001):

1. Neglect the problem in case of slight dusting.
2. Apply surface hardeners to improve wearing surface resistance in case of medium dusting.
3. Apply *Patching of Surfaces Procedure* in case of severe dusting.

• Preventive Solutions (ACI 302.1R-04, 2004; ACI 304R-00, 2000):

1. Supply high quality concrete mixtures.
2. Produce the mixture with the lowest practical water content.
3. Remove water of bleeding as soon as possible and prior to surface finishing.
4. Ensure hard surface troweling.
5. Avoid mixture segregation.
6. Avoid concrete overworking.
7. Perform effective curing and weather protection.

G. Scaling of the Surface:

Flaking or peeling away of the hardened pavement surface. The intensity may vary from light exposure of the coarse aggregate to the detachment of covers of the mortar up to about 100mm across and loss of aggregate particles (Stock, 1988; ACI 116R-00, 2000).

Causes (ACI 224.1R-07, 2007; ACI 302.1R-04, 2004):

1. Poor quality concrete due to, high w/c(over 0.50), excessive slump for prevailing job conditions overworking of wet concrete, premature finishing operations, inadeuate curing, or low compressive strength at the surface.
2. Exposure of the pavement to frost action during early age strength (before attaining enough strength).
3. Low air-entrained content near the surface due to concreting during hot weather or due to over vibration.

• Instantaneous Solutions (Army Corps of Engineers, 2001; ACI 551R-01, 2001):

1. Apply *Patching of Surfaces Procedure.*
2. In extreme cases, remove and reconstruct the defected pavement.

• Preventive Solutions (ACI 224.1R-07, 2007; ACI 302.1R-04, 2004):

1. Adopt high quality concrete mixtures.
2. Produce the mixture with the lowest practical water content.
3. Perform effective curing and weather protection.
4. Avoid concrete overworking.

H. Honeycomb Formation:

Irregular air voids condition appears at the extracted testing cores or at the side faces of pavement slab after removing of the forms (ACI 116R-00, 2000; ACI 214.4R-03, 2003).

Causes (ACI 224.1R-07, 2007; ACI 309.2R-82,1982):

1. Low concrete slump during concreting.
2. Congested reinforcement can obstruct the flow of the plastic concrete.
3. Impropercompaction or inadeuate vibration at the edges due to restriction by side forms.
4. Using of not lubricated side forms.
5. Bad grading of the concrete mixture.

• Instantaneous Solutions (Republic of Iraq, 1983; ACI 551.1R-05, 2005):

1. Fill any honeycomb at the edges with cement mortar composed of one part of cement to two parts of fine aggregate. Chemicals that provide bond between the new and the old concrete can be added to the mortar to improve its behaviour.
2. If extreme honeycombs are noted at testing cores, additional cores can be taken to check the pavement slab conditions. The additional cores shall be checked and tested by crushing test if they do not comply the reuired strength, the pavement shall be removed and reconstructed correctly without extra payment.

• Preventive Solutions (ACI 318M-08, 2008, Stock, 1988):

1. Select enough workable,well-graded mixtures using correct maximum aggregate size for properly compaction and finishing operations.
2. Ensure adequate compaction effort by adjusting the longitudinal speed of the vibrators with respect to their freuency.
3. Use the immersed vibrator type with spacing of 35-60cm among immersions through the slab and along the edges.
4. Use lubricated side forms.

I. Test Results Problems:

These problems can be diagnosed during the final inspection phase depending on the field and laboratory tests and measurements. This category includes the following problems:

I1. Concrete Strength is less than the Reuired:

The compressive strength of pavement concrete is less than strength specified in the contract reuirements depending on the instructions of the designer. The value of compressive strength can be obtained by testing a number of samples in accordance with ASTM C39 or AASHTOO T22. These samples are the cores cut from the pavement slab in the field in accordance with ASTM C42 or AASHTO T24; or the specimens fabricated during the construction process in accordance with ASTM C31 or AASHTO T14 (2005).

Causes (ACI 224.1R-07, 2007; Steven Kosmatka, 2005):

1. Incorrect concrete mix design.
2. Incompliance of the produced concrete with mix design formula.
3. Using dirt or salty water or adding extra water to the mixture during hauling or concreting.
4. Overworking of concrete after final setting.
5. Insufficient compaction efforts.
6. Insufficient concrete protection from harmful weather conditions.
7. Insufficient or late concrete curing.

• Instantaneous Solutions (14. Republic of Iraq, 1983; AASHTO, 1996):

Inform the designer about the deviation between the reuired and the field concrete compressive strength to evaluate the possibility of accepting or rejecting the results through reanalysis or redesign of the pavement. If the designer, according to calculations and constructional criteria, accepts the deviation, the pavement can be accepted with reasonable deduction from the price according to the conditions of the contract. Otherwise, the pavement shall be removed and reconstructed without any additional payment.

• ***Preventive Solutions (ACI 224.1R-07, 2007; Kosmatka, 2005):***

1. Produce concrete in accordance with the job mix formula using clean water, high uality aggregate, low water content, and proper additives. The crushed aggregate of ultimate maximum size is preferable to attain high compressive strength.
2. Avoid adding extra water to the mixture during hauling or concreting.
3. Complete all concreting stages as fast as possible to avoid overworking after final setting.
4. Ensure correct and sufficient compaction without over vibration.
5. Implement all arrangements to protect the concrete from harmful weather conditions.
6. Ensure fast, correct, and sufficient curing.

I2. Pavement Thickness is less than the Reuired:

The thickness of the pavement that measured in the field using the cut cores is less than the reuired by the drawings of the contract (Republic of Iraq, 1983; ACI 117-06, 2006).

• ***Causes (ACI 224.1R-07, 2007):***

1. Paving on uneven layer.
2. Adopting incorrect readings to the elevations of the layer under pavement (the sub-base layer).
3. Using forms with height less than the reuired.
4. Improper adjusting for the pavers.

• ***Instantaneous Solutions (Republic of Iraq, 1983; ACI 117-06, 2006; AASHTO, 1996):***

If the deviation of the thickness is less than 13 mm, the pavement can be accepted with reasonable deduction from the price according to the conditions of the contract otherwise, the pavement shall be removed and reconstructed without any additional payment.

• ***Preventive Solutions (ACI 117-06, 2006):***

1. Level the layer under pavement with no deviation more than tolerances and check elevations accurately.
2. Use standard forms of correct height.
3. Maintain, adjust and check the pavers prior to pavement construction.

I3. Improper Surface Texture:

Not textured or partially textured pavement surface that can cause skid hazards to the vehicles during pavement service. The average texture depth, as measured by sand patch test in accordance with ASTM E 965, must be not less than 0.75 mm between 24 hours and seven days after construction of the slab, and not less than 0.65 mm at or not later than six weeks before the road is open to the public traffic (Flaharty, 1988; ACI 302.1R-04, 2005).

Causes (ACI 330R-01, 2001; Flaharty, 1988):

1. Texturing by unskilled or careless staff, or by improper texturing method.
2. Performing texturing activity at late time after hardening of the concrete pavement surface.
3. Allowing rainwater access the pavement surface before the concrete has gained sufficient strength.

• ***Instantaneous Solutions (Flaharty, 1988):***

1. In case of large sections of high-speed road, the pavement surface can be remedied by retexturing using self-propelled multi-saw texturing machines to cut transverse grooves into the hardened concrete. For small areas, individual sawn grooves can be used.
2. In case of low-speed roads, surface dressing can be adopted. Laying surface dressing normally consists of applying a thin film of bituminous binder to the surface of the pavement, distributing a thin layer of aggregate chippings upon the binder, and rolling the chippings to ensure their adhesion to the surface.

• ***Preventive Solutions (ACI 302.1R-04, 2004; ACI 330R-01, 2001):***

1. Employ skilled staff to perform texturing activity according to proper method without any delay and before pavement surface hardening.
2. Protect the pavement surface from rainwater during the early stages until the concrete attain sufficient strength.

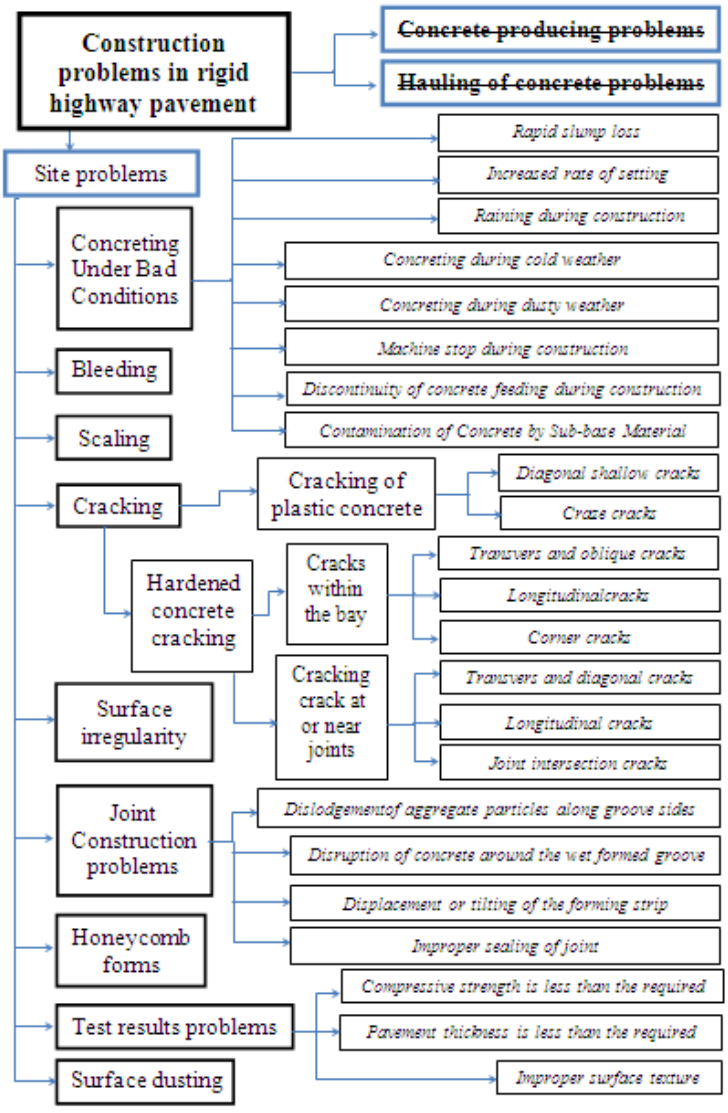

Fig. 1: Construction problem in rigid pavement diagram.

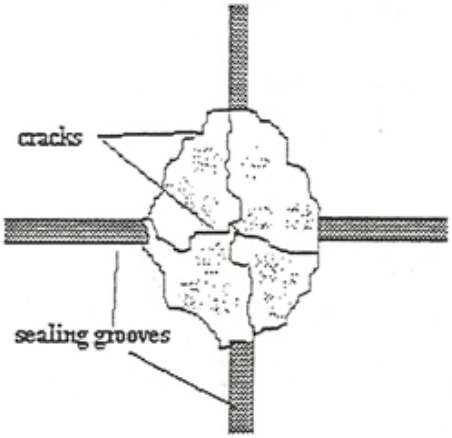

Fig. 2: Joint intersection cracks.

Table 1: Likely causes of the problems of concreting under bad conditions.

Causes	Concreting under bad conditions problems							
	A1	A2	A3	A4	A5	A6	A7	A8
Hot Weather (T>=30oC, low humidity, windy)	x	x						
Bad planning or managing of the pavement construction	x		x	x	x	x	x	
Unexpected weather changes			x	x	x	x		
Insufficient or incorrect weather information			x	x	x	x		
Low air temperature (T=< 5oC)				x				
Bad maintenance operation for the machines						x		
No maintenance record for the machines						x		
Concrete plant failure							x	
Inadequate materials at the plant site							x	
Concrete plant is far from the construction site							x	
The truck mixers fails or be restricted in traffic jam							x	
Bad communication among site, plant, and tucks operators							x	
Instable or disturbed sub-base layer								x
Incorrect handling by unskilled staff or incorrect tools								x
The sub-base layer is not covered by membranes								x
Incorrect vibrating method or immersing vibrator deeply which mix the sub-base material by the placed concrete								x

Table 2: Likely causes of cracking problems.

Causes	Cracking problems							
	C1.a	C1.b	C2.a	C2.b	C2.c	C2.d	C2.e	C2.f
Hot Weather (T>=30ºC, low humidity, windy)	x							
Insufficient or late curing	x	x	x	x				
Improper finishing by excessive floating or troweling		x						
Applying of cement powder on surface before finishing		x						
Restriction of pavement slab due to dowel bars restraint membrane at joints or due to excessive irregularities of roadbed or lack of separation			x	x	x	x		
High concrete shrinkage due to high water content			x	x				
High entrapped air content due to improper compaction			x					
Late sawing or low depth of contraction joint grooves			x	x		x		
High spaced contraction joints in unreinforced pavement			x	x				
Presence of an active alkali aggregate in mixture			x					
Improper protection from harmful weather conditions			x	x				
Trapping of stone pieces in sealed grooves					x			
Poorly compacted concrete around joint grooves						x		
Discontinuity of the joint groove in the vertical direction						x		
Misaligned top and bottom crack inducers							x	
Omission of bottom cracks inducers							x	
Discontinuity of the joints grooves at their intersections								x
Improper construction or disalignment of the joints								x

***Conclusion*:**

Construction problems in rigid highway pavement scan be classified into categories in accordance to common features and conditions among them. Many reasons can cause these problems during the construction process, but adopting of good prepared roadbed, high uality materials, verified euipment, skilled staff, and perfect management plan can eliminate the expected problems. However, when the problems occur, many solutions can be adopted to control them. The knowledge prepared in this paper can be used as a guide for the novice highway engineers in the sites of rigid pavement construction to control and to avoid such problems. Moreover, this knowledge can be verified by human experts in the domain of rigid pavements and to be coded as a knowledge-based expert system.

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