مجلة بحوث البناء والطرق

المجلد (19)
ديسمبر 2015

الرقم الدولي المعياري
ISSN 1858-5019

اسباب تأخير اكتمال مشاريع التشييد السودانية عن حينها
(من منظور المقاولين و الاستشاريين)

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مستخلص:

يتوقع اصحاب المشاريع و المقاولون و الاستشاريون اكتمال مشاريع التشييد خلال فترة محددة و بتكلفة محددة و جودة محددة لتؤدى تلك المنشات وظائفها كما اريد لها. لوحظ ان ظاهرة عدم اكتمال المشاريع الهندسية فى السودان فى حينها اصبحت ظاهرة مالوفة. لافعال طرفى العقد و الاستشارى وعوامل البيئة الخارجية اثر واضح فى تاخير اكتمال المشاريع الهندسية. حدد البحث 42 سببا يعتقد انها اهم الاسباب التى تؤدى الى تاخير اكتمال المشاريع الهندسية و يمكن الحاق تلك الاسباب بقصور فى مسؤليات طرفى العقد او البيئة الخارجية. تم تقسيم الاسباب الى اربع مجموعات تمثل قصور بمسئوليات المقاول او صاحب العمل او الاستشارى او مساهمة البيئة الخارجية لتاخير اكتمال المشروع فى حينه.. طلب من عينة المقاولين و الاستشاريين ترقيم الاسباب من خلال مقياس ليكارت ذات الخمس نقاط. وضحت الدراسة تماثلا لمتوسطى مؤشرى الاهمية النسبية لعينة الاستشاريين و المقاولين و ذلك بوضع 76 % من تلك العوامل فى ثلاث فئات بناء على قيم مؤشرات الاهمية النسبية للاسباب. تم تحديد احد عشر سببا و يتوقع مراقبة تلك الاسباب بواسطة طرفى العقد و الاستشارى منعها من الحدوث ليؤدى مجموع سلوكهم و افعالهم الى تقليل معدلات تاخير اكتمال المشاريع الهندسية عن حينها فى السودان.

Abstract:

Construction projects are expected to complete on time, within budget, within quality in order to fulfill its defined functions. In Sudan, it has been noticed that delay of construction projects is natural phenomenon. Actions or in-actions of contract parties, consultants coupled with external environmental factors contribute to construction delays. 42 construction delay main causes that could be attributed to client's, contractor's, consultant's or external environment's action / in-action. The same causes were divided into four groups that depict inefficiency and/ or ineffectiveness of the stakeholders. Contractors and consultants were asked to rank them on Likert's five point scale. The ranking process revealed categorizing %76 of the main causes in a pre-determined pin. Most of those causes were also attributable to responsibilities of contract parties. Eleven causes were marked as the most prevailing causes that contribute to construction delays. It's expected that parties will carefully manage those eleven causes during construction phase in order to decrease rates of construction delay.

Key words:

Construction delays, Conventional Construction Contracts, Pro-active plan, Re-active plan, Construction baseline time, Construction as built time, Construction time over run.

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1 . المقدمة:

بنهاية الالفية الثانية، تساءل الباحثون فى مجال ادارة زمن المشروع:
هل الجدولة القاعدية و زمن المشروع جزء من العقد؟
ما هو اثر عدم التزام طرفى العقد بالجدولة القاعدية؟
ما هو اثر تأخير اكتمال المشروع عن حينها على المقاول او صاحب المشروع؟
اى طرفى العقد له الحق فى استعمال الزمن الفائض لانشطة المشروع غير الحرجة دون ان يترتب عليه اى اثر؟
مسؤلية من ان يكتمل المشروع خلال الفترة المحددة؟

ان عنصر الزمن بالنسبة للمشاريع الهندسية ضرورى و لابد من الاهتمام به حتى لا يتعرض طرفا العقد الى الخسائر. يؤكد ثيودور ترونر و اخرون اهمية التنبؤ بالمخاطر التى يمكن ان تحدث اثناء تنفيذ المشاريع و التى سوف تكون لها اثرا واضحا فى زيادة زمن المشروع [1]. ان اطراف العقد يولون عناية خاصة لاكمال المشروع خلال الفترة المحددة. يؤثر كل من عدد ايام العمل الاسبوعية و العطلات القومية فى حساب فترة العقد. اخيرا يلاحظ ان القيمة الحالية لمنافع المشروع و معدل العائد الداخلى هما دوال فى زمن المشروع و يتغيران بتغيير زمن المشروع لتحدثان تغييرات جوهرية بدراسة جدوى المشروع. ولاهية اكمال المشاريع خلال المدة المحددة، افرد معهد ادارة المشروعات بدليله المعرفى لادارة المشاريع فصلا بإسم ادارة زمن المشروع [2].

1.1 تعريف تأخير اكمال المشروع عن حينها (Construction delays) :

ان كلمة التاخير تعنى حدوث النشاط بعد الفترة المتوقعة ولذلك فإن تعريف تأخير إكمال المشروع هو تسليم المشروع لصاحب العمل بواسطة المقاول وبحضور الاستشارى بعد ان انقضاء فترة التشييد المنصوص عليها فى العقد المبرم بين صاحب العمل والمقاول على ان يسبق ذلك اجراء التجربة التشغلية للمشروع وهو ايضا يعنى الفرق فى الزمن بين الزمن الذى اكتمل فيه المشروع والزمن المحدد فى العقد لانهاء المشروع . هذا التعريف يفترض تسليم المشاريع غير المتأخرة فى أو قبل الزمن المحدد لانهاء المشروع حسب العقد .

2.1 الاطار العام للدراسة:

اهتمت هذه الدراسة باسباب تاخير تسليم مشاريع البناء و التشييد فى السودان عن حينها و حاولت تعداد تلك الاسباب. لوحظ اختلاف الباحثين فى تبويب تلك الاسباب. فضل الباحث تبويب تلك الاسباب بناء على مصادر المخاطر بصناعة التشييد (صاحب العمل و الاستشارى، المقاول و البيئة الخارجية للمشروع) [3]. اوضح البحث اهمية تسليم المشاريع خلال الفترة المنصوص عليه بالعقد. قسم تاخير اكتمال المشاريع الى تاخير غير مسبب ينتج عن عدم الالتزام اطراف العقد بمعدلات الاداء وفق الجدولة القاعدية ، تاخير مسبب لا يمنح طرفى العقد اى تعويض مادى و تاخير مسبب يمنح الطرف المتضرر زمنا اضافيا و تعويضا ماديا بقيمة الضرر الناتج عن افعال ارادية للطرف المخل. تم تصميم استبيان و وزع على عينة من الاستشاريين و المقاولين. استعمل مدرج ليكارت (Likert) لحساب الاهمية النسبية لاى سبب يؤدى الى تاخير تسليم المشروعات فى السودان من منظور المقاولين و الاستشاريين و التعرف على اهمها وفق نظرية باريتو(4) (Pareto Law]. تم تحديد احد عشر سببا ذات اهمية نسبية اعلى و التى يعتقد انها تؤدى الى 80% من زيادة زمن اكتمال المشروع عن الجدولة القاعدية.

3.1 اهداف الدراسة:

تهدف هذه الدراسة الى التعرف على اهم اسباب تأخير اكتمال المشاريع فى حينها و من ثم استحداث علاقة بينها و مسؤليات طرفى العقد لادارتها وفق الاهمية النسبية لها من حيث:

- التعرف على المجموعات (العوامل) التى يمكن ان تساهم فى زيادة زمن المشروع عن الجدولة القاعدية
- تنبيه مدراء المشاريع و طرفى العقد على العمل باستمرار لادارة الاسباب ذات الاهمية النسبية الاعلى و منعها من الحدوث (او العمل على ازالة او تقليل اثارها ان حدثت) حتى يكتمل المشروع خلال فترة الجدولة القاعدية
- تنبيه اصحاب المصلحة الى الاثار الاقتصادية التى يمكن ان تترتب على المشروع ان تجاوز الفترة الزمنية المحددة للتشييد نتيجة لصعوبات كان يمكن تجاوزها
- اهمية تدوين زمن التاخير الذى يحدث اثناء التنفيذ للانشطة الحرجة باستمرار و التعرف على اسبابها مع توضيح العامل (العوامل) المساهم فى حدوثه

4.1 الافتراضات:

- واقعية الجدولة القاعدية (الاساسية) فى تمثيل موارد طرفى العقد لحظة التوقيع على العقد و معرفة طرفا العقد بالاثار التى تترتب على المشروع اذا تاخر تنفيذه عن فترة الجدولة القاعدية
- امكانية التعرف على الطرف المخل ببنود العقد من خلال مستندات المشروع اليومية اثناء التنفيذ على ان يؤدي ذلك الاخلال الى زيادة فى زمن المشروع
- معرفة و اجادة و اكتمال علوم وتقنيات ومهارات فريق المشروع و تعاون طرفا العقد لجنى منافع المشروع المحددة بدراسات الجدوى كحد ادنى و يفضل اغتنام الفرص لزيادة تلك المنافع

2 . الدراسات السابقة:

اختلف الباحثون فى تعداد الاسباب التى تؤدى الى تاخير اكتمال مشاريع التشييد عن حينها. وقد اتفق ان الاسباب اما ان تنبع من البيئة الداخلية او الخارجية للمشروع. ان حدوث الاسباب اثناء التنفيذ تغير من انسياب معدلات المدخلات عن تلك المعدلات المخطط لها بالجدولة القاعدية.

هنالك عدة دراسات تناولت هذا الموضوع و تشترك فى تحديد الاسباب التى تؤدى الى تاخير اكتمال المشاريع. تناول الباحث ورقتين لكل من ابن عباس [5] و مورالى [6] بالتفصيل. فإبن عباس عدد سبع و خمسين سببا يمكن ان تؤدى الى تاخير اكتمال المشاريع عن حينها و تم ادراجها فى ثمان مجموعات (المواد، العمالة، الاليات، التمويل، المقاول، صاحب المشروع، الاستشارى و القوة القاهرة). أما مورالى و ياو فعددوا ثمان و عشرين سببا يمكن ان تؤدى الى تاخير اكتمال المشاريع عن حينها و تم ادراجها فى ثمان مجموعات (صاحب المشروع، المقاول، الاستشارى، المواد، العمالة، عوامل العلاقات التعاقدية، العوامل الخارجية و عوامل خاصة بالعقد). الجدول (1) ادناه يوضح الاختلافات فى التقسيم الى مجموعات لدى كل من ابن عباس و مورالى. ايضا تناول اديتى ديناكار [7] فى بحثه تحليل التأخير فى تنفيذ مشاريع التشييد (Delay Analysis in Construction Projects) سبع مجموعات.

الجدول (1) الاختلافات فى تقسيمات ابن عباس و مورالى

رقم	مجموعات ابن عباس (8 factors)	مجموعات مورالى (8 factors)	ملحوظات
1	المواد (delays related material of factors)	factors related material	
2	العمالة (delays related labour of factors)	equipment and labour factors related	
3	الاليات (factors of equipment related delays)	-	
4	التمويل (factors of finance related delays)	-	
5	االمقاول (factors of contractor related delays)	contractor related factors	
6	صاحب المشروع (factors of client related delays)	Owner related factors	
7	الاستشارى (factors of consultant related delays)	consultant related factors	
8	البيئة الخارجية (factors of external related delays)	External factors	
9	-	Contract related factors	
10	-	Contract relationship related factors	

اغلب الدراسات السابقة تنقصها ايجاد علاقة بين اسباب تاخير اكتمال المشروعات عن حينها و العوامل التى تؤدى الى حدوث تلك الاسباب. يلاحظ من الجدول (1) اعلاه، كانما التاخير يحدث نتيجة للمجموعات (9،4،3،2،1و 10) دونما اية مسؤلية للمجموعات (5، 6، 7 و8). ايضا يلاحظ اختصار عامل البيئة الخارجية بالقوة القاهرة. الا انه و لغرض هذه الدراسة ضمت مجموعة البيئة الخارجية كل من الظروف البيئية القاهرة و توريد المواد المحلية و غير المحلية للمشروع ومدى توفر المواد بالسوق المحلى و سعر تلك الموارد لحظة تنفيذ الانشطة و معدلات الفائدة و التى تتاثر بمعدلات التضخم و اضراب العاملين تحت قيادة منظماتهم القطرية .حاولت هذه الدراسة الى استحداث علاقة بين الاسباب و مسؤليات طرفى العقد و الاستشارى و البيئة الخارجية للعقد. يتم ذلك بارجاع اسباب التاخير الناتجة عن المجموعات (9،4،3،2،1و 10) الى مصادرها بالمجموعات (5، 6، 7 و8). ايضا يلاحظ عدم تناول الدراستين(الورقتين) لاهمية علوم الاتصال و سلوك المجموعات اعلاه فى التاثير على اكتمال المشاريع فى حينها. يرى كثير من الكتاب و ايضا كاتب هذا البحث أهمية اتصالات المشروع و العمل وفق سلوك موجب للوصول الى اهداف المشروع. اخيرا، يمكن ان يؤدى سوء ادارة اتصالات المشروع الى نتائج غير مرجوة للمشروع حيث يعتقد اديتى ديناكار ان تاخير اكتمال المشروع هو نتيجة لسوء ادارة اتصالات المشروع [7]. ان الادارة الجيدة تذكر فرق المشروع المختلفة بمسؤلياتهم تجاه العقد من حيث زمن و جودة و تكلفة انشطة المشروع علما بان مخرج اى نشاط يكون مدخلا للانشطة اللاحقة و التى قد ينفذها فريق مختلف.

3.تنفيذ البحث

1.3 ترتيب اسباب تأخير تنفيذ المشاريع

اوضح الن لارسن ان الاداء الممتاز و الفعال يتطلب علوم و تقنيات و مهارات و موارد و خطط و سلوك ترتكز على قيم محددة و ذلك وفق النموذج ادناه[4]:

الرؤية +العلوم والمهارات+التحفيز و الدافعية+الموارد (مواد و اليات و موارد بشرية)+الخطة و المتابعـــة = تغيير منشود (1)

من خلال النموذج اعلاه، لابد من التعرف على المخاطر و المشاكل التى يمكن ان تحدث و تمنع انسياب المدخلات حسب المتوقع بالجدولة القاعدية للمشروع و كذلك العوامل التى تؤدى الى حدوث تلك المخاطر . ايضا، على اطراف العقد متابعة مؤشرات منع حدوث تلك المخاطر باستمرار. يؤكد

الباحثون ان التزاوج بين الجدولة القاعدية و جدولة التنفيذ الحقيقى هو السبيل الامثل لتقييم تاخير اكتمال المشروع و التعرف على الطرف المخل ببنود العقد و حثه على العمل على استحداث تغيير فى معدلات اداءه ليتمكن الطرفان من تسليم المشروع فى حينه.

لغرض هذه الدراسة، تم تحديد اهم 42 سببا يمكن ان تؤدى الى تاخير فى زمن اكتمال المشروع. تم تقسيم الاسباب الى اربع مجموعات وفق الجدول (2) ادناه لتمثل اى مجموعة افعال او اقوال او سلوك ذلك العامل:

الجدول (2) مجموعات العوامل ذات الصله بتأخير اكتمال مشاريع التشييد عن حينها

المجموعة	العامل (اسباب ذات صله بتأخير تسليم مشاريع التشييد):
الاولى	المقاول (افعاله او اقواله او سلوكه سببا فى حدوثها)
الثانية	البيئة الخارجية سببا فى حدوثها
الثالثة	الاستشارى (افعاله او اقواله او سلوكه سببا فى حدوثها)
الرابعة	صاحب العمل (افعاله او اقواله او سلوكه سببا فى حدوثها)

ايضا، تم تقسيم الاسباب الى ثلاث فئات بناء على الترتيب التنازلى لمعاملات الاهمية النسبية للاسباب و قانون باريتو (الجدول (3)):

الجدول (3) مدى مؤشر الأهمية النسبية لاى سبب (RII) و رد الفعل الادارى المتوقع

حقائب الفئات (نسبة عدد الاسباب)	مساهمة الفئة فى تاخير اكتمال المشروع	رد الفعل الادارى المتوقع (Managerial Response)
حقيبة الفئة الثالثة (يحوى ≈ 20 % من الاسباب)	المساهمة منخفضة جدا"	رد فعل ادارى سلبى (Re-active) (No Plan)
حقيبة الفئة الثانية (يحوى ≈ 60% من الاسباب) يحوى ≈ 20% من الاسباب	المساهمة منخفضة	رد فعل ادارى ابتكارى مبسط (Very Simple (Pro-active) Plan)
يحوى ≈ 20% من الاسباب	المساهمة متوسطة	رد فعل ادارى ابتكارى بسيط (Simple Plan) (Pro-active)
يحوى ≈ 20% من الاسباب	المساهمة كبيرة	رد فعل ادارى ابتكارى مفصل (Pro-active (Detailed Plan)
حقيبة الفئة الاولى (يحوى ≈ 20 % من الاسباب)	مساهمة كبيرة جدا	رد فعل ادارى ابتكارى دقيق التفاصيل (Pro-active) (Very Detailed Plan)

حقيبة الفئة الثالثة (اللون الازرق) خاصة باسباب تاخير اكتمال المشاريع ولها معامل اهمية نسبة منخفض جدا و التى لا يتوقع ان يوليها فريق المشروع اهمية عند مرحلة التخطيط علما بان حل المشاكل الناتجة عنها مقدور عليه وقليلة الاثار على المشروع (8 اسباب ≈ 20 % من الاسباب). هى اذن اسباب ذات مساهمة منخفضة جدا فى زيادة زمن المشروع حيث يلازمها رد فعل ادارى سلبى

عند مرحلة التخطيط(Re–active). تتميزهذه الاسباب بانها مخاطر و مشاكل قليلة التكرار اثناء التنفيذ و يمكن التنبا بحدوثها بدرجة كبيرة.

حقيبة الفئة الثانية (اللون الاصفر) خاصة باسباب تاخير اكتمال المشاريع ولها معامل اهمية نسبة متدرجة (من منخفضة الى كبيرة) و التى يتوقع ان يوليها فريق المشروع اهمية عند مرحلة التخطيط والتنفيذ و هى غالبا تكون من مسؤليات الادارة الوسطى عند مرحلة تنفيذ المشروع (26 سببا ≈ 60 % من الاسباب). هى اذن اسباب ذات مساهمة تتدرج من منخفضة الى كبيرة فى زيادة زمن المشروع حيث يلازمها رد فعل ادارى ابتكارى (Pro–active). تتميزهذه الاسباب بانها مخاطر و مشاكل يمكن ان تحدث باستمرار اثناء تنفيذ النشاط الواحد او الانشطة المتوازية.

اخيرا، حقيبة الفئة الاولى (اللون الاحمر) خاصة باسباب تاخير اكتمال المشاريع و معامل الآهمية لنسبة لها هو الاعلى (كبيرة جدا) و التى يتوقع ان توليها الادارة العليا للمشروع اهمية قصوى عند مرحلتى التخطيط و التنفيذ (8 اسباب ≈ 20 % من الاسباب). و يشير باريتو لاهمية ان تشعر اطراف العقد بالمسؤلية الكبيرة والمحاسبة حتى يمكن الايفاء بمعدلات الاداء حسب الخطة . و بما ان مصادر المشاكل و المخاطر كثيرة، فيطلب من الادارة العليا لاطراف العقد الاهتمام باسباب حقيبة الفئة الاولى و التى يعتقد انها تؤدى الى من الزيادة فى زمن المشروع[4] بنسبة 80 %

تم ترتيب اسباب تاخير اكتمال المشاريع عن حينها وفق الاهمية النسبية لها من منظور المقاولين او الاستشاريين. هذا الترتيب سوف يساعد الاداريين فى تركيز جهودهم بوضع خطط تفصيلية لادارة العوامل التى لها الاهمية النسبية الاعلى (حقيبة الفئة الاولى). ويحبز عدم بذل اى مجهود لوضع خطط لادارة العوامل ذات مؤشرات الاهمية النسبية الادنى (حقيبة الفئة الثالثة) و يمكن ترك تلك الاسباب الى ان تكون واقعا ليتم حل مشاكله. العوامل التي لها مؤشرات اهميه نسبيه متدرجه (من منخفضة الى كبيرة) والتى تم ادراجها بحقيبة الفئة الثانية فيجب على الادارة الوسطى وضع خطة لادارتها.

بعدها تم تصميم استبيان و وزع اكثر من 114 نسخة منه على للمقاولين و الاستشاريين. ارجع المقاولين 73استبيناً بينما ارجع الاستشاريون 31 استبيناً . تم تحليل محتويات الاستبيانات بواسط برنامج اكسل. استعمل الباحث مدرج ليكارت (Likert) لتحليل البيانات و إيجاد متوسط مؤشر الاهمية النسبية لاى من اسباب تاخير تسليم المشروعات وفق معادلة مؤشر الأهمية النسبية لاى سبب (Relative Importance Index (RII)):

$$RII = \frac{\sum_1^5 a_i f_i}{5 \sum_1^5 f_i}$$

a_i – 1,2,3,4,5 (Likert scale)

fi = frequency of a response corresponding to a_i

من خلال ادبيات البحث اعلاه، الشكل (1) ادناه يوضح طريقة البحث:

الشكل (1) طريقة البحث

2.3 اهمية اكتمال المنشات خلال الفترة المحددة بالعقد:

اثبتت الدراسات انه يصعب تقليل زمن تاخير اكتمال المشاريع دون العمل على التعرف على الاسباب التى تؤدى الى حدوث التاخير[5]. ان التعرف على تلك الاسباب يجعلنا نمنع حدوث او ندير المخاطر التى تؤدى الى حدوث التاخير بفعالية. ان تأخير اكتمال المشاريع يحدث حينما يساهم صاحب العمل او المقاول (او احد منسوبيهم) او البيئة الخارجية للمشروع في انتاج بيئة مثالية للمخاطر لزيادة زمن المشروع. لابد ان تاتى زيادة زمن المشروع من خلال خط المسار الحر القاعدى. ان زيادة او نقصان زمن المسارات الاخرى غير القاعدية لا تؤثر فى الزمن الكلى للمشروع الا اذا تحولت تلك المسارات الى مسارات حرجة بدلا او مع خط المسار الحرج القاعدى. ان الجدولة القاعدية هى ضمن مستندات العقد حيث يلتزم طرفا العقد بموجبها على انشاء حقوق و واجبات بينهما [3]:

- عدم التاثير على الجدولة بطريقة سلبية من خلال افعالهم (او عدم افعال) او اقوالهم
- عدم تعطيل او ايقاف انشطة الطرف الاخر
- التعاون و الايفاء بالالتزامات الناشئة عن الجدول

هنالك مرجعيات كثيرة و المكتبات ذاخرة بادبيات ادارة زمن المشروع التى تمكن اطراف العقد

بالعمل سويا لاكمال المشروع خلال الفترة المحددة بالعقد (baseline time). تستخدم مخططات ادارة زمن المشروع المعادلة البسيطة التالية لحساب زمن اى نشاط:

$$Time = \frac{Q}{r \times n}$$

حيث ان : Time زمن النشاط، Q كمية النشاط ، r معدل اداء الفريق الواحد و n عدد الفرق العاملة لانجاز النشاط

بتجزئة المشروع الى انشطة و بالاستعانة بمنطق تسلسل تنفيذ الانشطة فيما بينها يمكن انشاء جدولة التحليل الشبكى للمشروع. باسعمال المعادلة اعلاه، يمكن حساب زمن اى نشاط و من ثم تحليل جدولة التحليل الشبكى لاستخلاص خط (خطوط) المسار الحرج و الزمن الفائض للانشطة الاخرى و الزمن الكلى للمشروع (baseline time). بناء على نتائج بحث إبراهيم بن عبدالله الحماد و اخرون [8] فقد تم حسم ملكية المقاول للزمن الفائض المصاحب لانشطة المشروع غير الحرجة و يجوز لصاحب العمل استغلال الزمن الفائض بعد موافقة المقاول (مدفوع او غير مدفوع القيمة). تفترض تقنية التحليل الشبكى واقعية البيانات لتمثل مقدرات اطراف العقد الحقيقية من حيث:

- توفير المقاول للموارد المطلوبة بالموقع وفق كميات و جودة الجدولة القاعدية
- التزام صاحب العمل باداء واجباته وفق المطلوب بالجدولة القاعدية للمشروع
- البيئة سوف تساعد صاحب العمل و المقاول سويا على حل المواضيع و المشاكل الى تعترض سبيل العمل بل و العمل على اغتنام الفرص التى تلوح من حين لاخر.

ان احدى المشاكل الدائمة بصناعة التشييد هى انشاء جدولة تمثل التقدم الحقيقى لعمليات التشييد بالموقع. تتطلب جدولة التقدم الحقيقى لعمليات البناء عند بدء مرحلة التنفيذ، عمليات قياس معدلات الاداء الفعلية للفرق العاملة و مقارنتها مع معدلات الاداء القاعدية اعلاه للتنبأ بامكانية اكتمال المشروع خلال الفترة المحددة. تستعمل نتائج القياسات اعلاه لاتخاذ قرارات تصويبية لنجاح المشروع. ايضا يمكن استعمال جدولة التقدم الحقيقى لعمليات التشييد بالموقع فى التعرف على الطرف المخل ببنود العقد وفق اعراف صناعة التشييد. بناء على نتائج بحث لم ينشر يلاحظ ان نسبة الزيادة فى زمن المشروع فى السودان خلال الفترة (1990 – 2002 م) اكثر من 100 % [9]. تجرى مجموعة استاندش(Standish Group) دراسات عن مشاريع تقنية التكنولوجيا بصفة دورية لتصنف المشاريع الى مشاريع ناجحة، مشاريع تواجه صعوبات و مشاريع فاشلة. تؤكد النتائج باستمرار ان المشاريع السنوية الفاشلة تمثل اكثر من 20 % حيث تؤدى الى اهدار موارد مقدرة [10]. ايضا، تؤكد دراسات كثيرة ان لزيادة زمن المشروع اثار كثيرة منها:

- فقدان او تقليل انتاجية الفرق بالموقع (baseline team performance rates)
- زيادة تكلفة المشروع عن التكلفة القاعدية (baseline cost)
- بروز نزاع قد يؤدى الى التاثير فى المشروع او الغاءه بواسطة اليات تنشا لهذا الغرض (الغاء، تحكيم، مقاضاة)

3.3 انواع تاخير اكتمال مشاريع التشييد من حيث المحاسبية :

1.3.3 **تاخير غير مسبب** (Non-excusable Delays) :

هو تاخير تسليم المشروع الذى ينتج عن عدم التزام احد طرفى العقد بمعدلات الاداء وفق الجدولة القاعدية و ذلك لاسباب تخص اما المقاول (اخطاء فى التشييد، عدم الالمام بالظروف البيئية للمنطقة، ....). او يمكن ان يحدث التاخير الناتج عن عدم ايفاء صاحب العمل بالتزاماته حيث يضطر المقاول الى تقليل معدلات الاداء الى مستوى دون الاداء القاعدى. عند حدوث اى من الحالتين، يجوز للطرف المتضرر المطالبة بالتعويض من الطرف الاخر لدفع التكلفة الناتجة عن الزمن

الاضافى لتكملة المشروع (استعمال الموارد بدون كفاءة). عند مواجهة مشاكل او صعوبات اثناء التنفيذ بواسطة احد طرفى العقد، يؤدى ذلك الى عدم التزامه بالقيام بواجباته فى حينها.

ايضا يمكن لاى من طرفى العقد تعطيل العمل دون ان يؤدى ذلك الى تاخير تسليم المشروع فى حينه و لكن يمكن ان تكون مكلفة للطرف الاخر كايقاف عمال المقاول الذين يؤدون نشاطا غير حرج(construction disruption). و بما ان مبدا تعاون طرفى العقد يلزمهما بالعمل بالطاقة القصوى، فانه يمكن للمقاول ان يعوض بقيمة الخسائر الناتجة عن تعطيل العمل بواسطة صاحب العمل. يطلب من الطرف المدعى اثبات او ابراز البيانات و الحقائق التى تثبت ان التاخير نتج عن افعال او اقوال الطرف الاخر و تاثير ذلك على تكلفة المشروع [11]. ان الالتزام بتفعيل بنود التعويض بالعقود الهندسية، يؤدى الى الزام الاطرف بالعمل على الايفاء بالتزاماتهم نحو العقد و التركيز صوب الهدف (اكتمال المشروع خلال الفترة المحددة و بالتكلفة المحددة و بالجودة المطلوبة) و من ثم استعمال موارد الاطرف بكفاءة و فعالية.

2.3.3 **تاخير مسبب غير قابل للتعويض**(Excusable Non -Compensable Delays)

هو تاخير اكتمال المشروع الذى ينتج عن احداث لا يمكن االتنبا بها و التى تحدثها البيئة الخارجية للمشروع (القوة القاهرة). ان اسباب التاخير غير القابلة للتعويض هى خارجة عن افعال طرفى العقد. استقر العرف الهندسى و الذى يوافقه المنطق على منح طرفى العقد تعويضا ممثلا فى زمن اضافى على ان يتقاسم طرفا العقد المخاطر و الاثارالمترتبة عن التاخير.

3.3.3 **تاخير مسبب قابل للتعويض** (Excusable Compensable Delays)[11]:

هو تاخير تسليم المشروع الذى ينتج عن افعال او ارادة احد طرفى العقد (اوامر تغييرية ، ايقاف العمل لظروف ما، ....). فى مثل هذه الحالة يتم تعويض الطرف المتضرر بقيمة الضرر الناتج عن افعال ارادية للطلرف الاخر. ليتم الموافقة على التعويض، لابد ان يتحقق شرطين اساسيين:

- ينتج التاخيرعن افعال او ارادة الطرف الاخر(لا يحق لصاحب العمل بمطالبة تعويض فى حالة حدوث تاخير فى خط المسار الحرج بل عليه اولا ان يثبت ان التاخير نتج عن افعال او عدم افعال او اقوال المقاول)
- ان يؤثر التاخيرعلى تكملة المشروع و تشغيله خلال فترة العقد القاعدى (فى حالة عدم التاثير على تشغيل المشروع، يتم اداء النشاط خلال فترة اصلاح العيوب)
- الجدول (4) ادناه يوضح مسؤليات اطراف العقد فى تحمل تبعات تاخيراكتمال المشاريع:

الجدول (4) مسئوليات أطراف العقد ونتائج عدم إكتمال المشروع خلال الزمن المحدد بالعقد

مصدر الاساسى للتاخير	نتائج عدم التسليم خلال الزمن المحدد بالعقد
المقاول (اقواله او افعاله)	لا يمنح المقاول تكلفة التاخير او زمن اضافى و يمكن ان يدفع تعويض لصاحب العمل
الاستشارى	يمنح المقاول زمن اضافى و تكلفة التاخير
صاحب العمل	يمنح المقاول زمن اضافى و تكلفة التاخير
صاحب العمل و المقاول (delays concurrent)	يمنح المقاول زمن اضافى فقط دون تكلفة التاخير
البيئة الخارجية (القوة القاهرة)	يمنح المقاول زمن اضافى فقط
البيئة الخارجية (طرف ثالث, نظم و لوائح)	يمنح المقاول زمن اضافى و تكلفة التاخير

4.3.3 زيادة معدلات الاداء (construction acceleration)**:**

فى بعض الحالات، قد يمنح المقاول تاخير مسبب غير قابل للتعويض (اضافة زمن) و لكن اذا طلب صاحب العمل زيادة معدلات الانجاز حتى يتمكن الطرفان من تسليم المشروع فى حينه، فان هذا الطلب يحول التاخير الى تاخير مسبب قابل للتعويض (construction acceleration). ايضا يمكن لصاحب العمل حث المقاول على زيادة معدلات الانجاز عن معدلات الجدولة القاعدية حتى يتمكن الطرفان من تسليم المشروع قبل الفترة المحددة. هنالك عدة طرق لزيادة معدلات اداء النشاط عن المخطط للايفاء بالتزام زمن لتسليم المشروع فى حينها منها [9]:

- زيادة ساعات العمل الرسمية خلال اليوم عن المخطط لها (overtime)
- زيادة عدد الورديات خلال اليوم عن المخطط لها (increase the number of shifts)
- زيادة عدد فرق النشاط خلال اليوم عن المخطط لها (increase number of teams)
- استعمال اليات و معدات ذات انتاجية اكبر عن المخطط لها
- استعمال طريقة اداء مختلفة عن المخطط لها

4.3 طرق تقليل زمن تاخير اكتمال المشاريع:

هنالك عدة اجراءات لابد من اتباعها بواسطة اصحاب العمل او الاستشاريين او المقاولين لانقاص معدلات تاخير تسليم المشاريع منها:

1.4.3 صاحب العمل و الاستشارى:

على صاحب العمل اختيار مقاول كفوء و ليس فقط بناءا على عرض تكلفة تشييد المشروع. يجب الاهتمام بخبرة المقاول و مقدراته التقنية و الادارية و موارده البشرية و المالية بحيث تتناسب و حجم و تقنيات انشطة المشروع [12]. يمنع صاحب العمل من اصدار توجيهات مباشرة لعمالة المقاول او الاستشارى و يحبذ اتباع اجراءات محددة لاصدار الاوامر التغييرية. العمل على دفع استحقاقات المقاول خلال الفترة المنصوص عليها بالعقد و اتخاذ القرارات الملائمة خلال فترة محددة [13].

على الاستشارى العمل على تصميم المنشاة خلال فترة دراسات الجدوى و العمل على تقليل اصدار الاوامر التغييرية. ايضا، عليه مراقبة و متابعة تنفيذ المشروع و توجيه المقاول و صاحب العمل على حل المشاكل و الصعوبات التى تواجه المشروع من خلال نتائج تحليل بيانات تنفيذ المشروع و الاستفادة من تلك النتائج لتصويب سيراداء التنفيذ. ايضا على الاستشارى مراقبة نتائج التجارب و تحليلها باستمرا ر لاتخاذ القرارات المتسقة مع بنود العقد [14].

2.4.3. المقاول:

عليه الإبتعادِ عن المشاريع التى تتطلب خبرات معقدة و التى يفتقرها فريق عمله. العمل على تعيين مديراً مقتدراً للمشروع من حيث العلوم والمهارات و التقنيات لتتوافق و متطلبات المشروع تخطيطا و متابعة. جعل عمليات التحطيط و التحفيز جزءا من ثقافة الشركة و تدريب العمال و الاهتمام بعمليات شراء المواد ذات الجودة المطلوبة [15]

3.4.3 طرفا العقد و الاستشارى:

عليهم العمل على مراقبة البيئة الخارجية للمشروع لادارة مشاكلها و مخاطرها لمصلحة المشروع. ايضا، العمل على زيادة معدلات اداء الانشطة الحرجة و شبه الحرجة من قبل المقاول لانجاز العمل مبكرا أو للتعويض عن وقت ضائع. لابد من تدوين لحظات و قياسَ فَترة التاخَير اثناء التنفيذ للانشَطة الحرجة و شبه الحرجة المتاثرة بالتاخير و توضيح اسبابه و الاثار المترتبة عنه حتى يتمكن اى طرف من تحقق ادعاء الطرف الثانى.

4 . تحليل البيانات (Data Analysis) و مناقشتها :

تم تقسيم عوامل تاخير تسليم المشاريع بناء على مسؤليات اطراف العقد (الجدول (1)). تم ترتيب اسباب تاخير اكتمال المشاريع عن حينها ترتيبا تنازليا بناء على معاملات الاهمية النسبية (RII) من وجهه نظر الاستشاريين او القاوليين:

- اتفقت عينة المقاولين مع عينة الاستشاريين في ترتيب 32 سببا (76 %) من الاسباب ذات التاثير على زمن المشروع وتم وضعها فى ذات الحقيبة (الفئة الأولى أو الثانية أو الثالثة)
- إختلفت عينة المقاولين مع عينة الاستشاريين فى ترتيب 10 سببا (24 %) و وضعوها في حقائب مختلفة .
- من الجدول (5) ادناه، يلاحظ اختلاف ترتيب السبب بالرقم المتسلسل (5) و السبب بالرقم المتسلسل (40) من الاستبيان بواسطة عينة المقاولين و عينة الاستشاريين بحيث:

الجدول (5) اختلاف ترتيب السبب رقم (5) و السبب رقم (40) من الاستبيان

رقم التسلسل بالاستبيان	العامل ذات التاثير على زمن المشروع	حقيبة الفئة (الترتيب) (الاستشاريون)	حقيبة الفئة (الترتيب) (المقاولون)
5	قلة تحفيز العمال وليست لديهم رغبه حقيقيه للأنجاز حسب معدلات الأداء المطلوبه	حقيبة الفئة الثانية (24) (متوسط الاهمية النسبية = 3.18)	حقيبة الفئة الثالثة (40) (متوسط الاهمية النسبية =2.57)
40	زياده سعر المواد بالسوق المحلي (fluctuation prices\inflation)	حقيبة الفئة الثانية (25) (متوسط الاهمية النسبية = 3.14)	حقيبة الفئة الثانية (9) (متوسط الاهمية النسبية = 3.30)

يوضح عينة الاستشاريين ان للبند (5) من الاستبيان اثر اكبر فى زيادة زمن المشروع من البند (40)، بينما يرى عينة المقاولين عكس ذلك تماما. يعتقد عينة المقاولين ان زيادة اسعار موارد البناء و التشييد تحدث نيجة لبيئة يصعب عندها الاحتفاظ بمعدلات اداء الخطة قبل معرفة من يتحمل الفرق فى الاسعار ! بما ان لقرارات صاحب العمل المالية و البيئة الخارجية للموردين اثر على معدلات اداء المقاول، يرى الباحث ان يعمل اطراف العقد على استحداث معادلة تضبط تكلفة الانشطة قبل التوقيع على العقد يلاحظ ايضا بالرغم من معرفة عينة الاستشاريين و عينة المقاوليين باسباب تاخيرتسليم المشاريع عن حينها الا ان تلك المعرفة لم توقف تاخير تسليم المشاريع الى الدرجة المتوقعة، لماذا؟

- يلاحظ ايضا عدم معرفة عينة الدراسة باهمية اتصالات المشروع حيث تم الاتفاق بواسطة العينتين بترتيب البنود (29، 4، 41) بحقيبة الفئة الثالثة بنهايات ترتيب الاسباب (41، 40، 35) !
- اتفق عينة المقاولين مع عينة الاستشاريين فى وضع خمس اسباب بحقيبة الفئة الاولى واختلفا فى تحديد ثلاث اسباب اخري لتكون جملة اسباب الفئة الاولى 9 سببا. حيث تري عينة الاستشاريين ان البنود (10، 19، 22) اكثر اهمية من البنود (31، 21، 16) بينما ترى عينة المقاولين عكس ذلك تماما. أما الباحث يري إضافة بنود الست بنود اعلاه لبنود هذه الفئة لتصبح جملتها (11) بندا (26 %). وهذا يتطلب من الادارة العليا لاطراف العقد الاهتمام بادارة اسباب حقيبة الفئة الاولى.
- اخيرا، اتفقت العينتان فى وضع ست اسباب بحقيبة الفئة الثالثة و اختلفتا فى تحديد ثلاثه اسباب أخري لتكون جملة اسباب الفئة الثالثة 9 سببا. حيث ترى عينة الاستشاريين ان البنود (3، 27) أقل اهمية من البنود (25، 5)، الا ان عينة المقاولين تري عكس ذلك تماما. يرى الباحث باضافة البنود الاربع اعلاه لتكون جملة بنود هذه الفئة (10) بندا (24 %). يلاحظ ان هذه الاسباب قليلة التكرار اثناء التنفيذ و لا يتوقع ان يكون اثرها كبيرا فى زيادة زمن المشروع.

بناء على التحليل اعلاه فانه تبق (21) سببا (50 %) بحقيبة الفئة الثانية. ولذلك يطلب من الادارة الوسطى لاطراف العقد الاهتمام بادارة اسباب حقيبة الفئة الثانية.

الشكل (2) ادناه يوضح حقائب الفئات المختلفة بعد اعادة توزيع الاسباب غير المتفق عليها بواسطة العينتين(الاستشاريين و المقاولين).

الشكل (2) حقائب الفئات المختلفة بعد اعادة توزع الاسباب غير المتفق عليها

الجدول (6) ادناه يوضح اهم الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان تكون افعال او اقوال المجموعات سببا فى حدوثها. رتبت الاسباب ترتيبا تنازليا من منظور الاستشاريين (حقيبة الفئة الاولى)

الجدول (6) اهم 26 % من الاسباب ذات الصله بتأخير تسليم مشاريع التشييد عن حينها

الرقم المتسلسل	اهم 26% الاسباب ذات الصله بتأخير تسليم مشاريع التشييد عن حينها	الاستشاري	المقاول
		المتوسط	المتوسط
35	صعوبة عملية يواجها المقاول لدفع قيمة المواد ، المستحقات المقاولين من الباطن	4.45	4.00
8	عدم دفع مستحقات المقاول من المصرفيات غير حقيقية خلال الفترة المتوقعه (الفترة المحددة بالعقد مثلاً)	4.05	4.30
34	عوامل ذات صلة بالصراعات المحلية أو الحروب توقف العمل	4.00	3.39
18	قلة خبرة المقاول أو سوء في التخطيط وضبط الجودة	3.95	3.39
22	مستحقات المقاول بالبنك وصعوبات فنيه وغالبا ما تكون متعلقه بلحظة التوقيع على العقد مما يؤدي الى تأخير عمليات الحصول إلى المعدات المتوقع	3.77	3.04
10	قلة خبرة المقاول في تقدير تكلفة المشروع	3.73	3.17
13	البنوك وصعوبات المقاول ذات كفيه فنيه وذات أعمال مكررة	3.68	3.43
19	تأخير إجراءات شراء المواد بواسطة المقاول الى ان يحين وقت تنفيذ النشاط بموقع المشروع (مثل تقدير زمن شراء و توريد المواد)	3.58	3.17
31	صاحب العمل قليل العلم و الخبرة بمشاكل صناعة التشييد و لا يهتم كثيراً بالتزامات التعاقد بينه وبين المقاول	3.55	3.43
16	التأخير في إصدار الأوامر التغيير بواسطة صاحب العمل والتي تؤدي الى زيادة زمن تنفيذ المشروع	3.55	3.35
21	عدم توفر المواد بالجوده المطلوبة بالسوق المحلي	3.27	3.35

الجدول (7) ادناه يوضح الاختلافات في ترتيب الاسباب بواسطه عينتي المقاول والاستشاري .

الجدول (7) الاختلافات فى ترتيب الاسباب بواسطة العينتين.

رقم البنود	الفئة المختارة (المقاولون)	الفئة المختارة (الاستشاريون)
27, 3	الثانية	الثالثة
25, 5	الثالثة	الثانية
16,21,31	الاولى	الثانية
10,19,22	الثانية	الاولى

الجدول (8) ادناه يوضح الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان تكون افعال او اقوال المقاول سببا فى حدوثها رتبت ترتيبا تنازليا. يرجى من المقاولين استعمال اليات و معدات جديدة وأن تكون نسبة اهلاكها وفق اسس علمية محددة الشئ الذي يزيد من كفاءة الاليات.

الجدول (8) الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان يكون المقاول سببا فى حدوثها

الرقم المتسلسل	الاسباب ذات الصله بتأخير تسليم مشاريع تشييد (المجموعة الاولى)	الاستشاري			المقاول		
		الإنحراف المعياري	معامل التباين	متوسط الاهمية النسبية	متوسط الاهمية النسبية	معامل التباين	الإنحراف المعياري
35	صعوبات مالية يواجهها المقاول (قلة تمويل و استعانة المقاولين من الباطن)	1.01	0.23	4.45	4.00	0.31	1.24
18	قلة خبرة المقاول أو سوء في التخطيط و تنسيق تجويد	1.21	0.31	3.95	3.39	0.38	1.31
22	استعانه المقاول بآليات و معدات قديمه متعطله لحظة الشروع على العقد	1.45	0.38	3.77	3.04	0.49	1.49
10	قلة خبرة المقاول في تقدير تكلفة المشروع	1.45	0.39	3.73	3.17	0.48	1.56
13	آليات ومعدات المقاول ذات تقنيه قديمه وذات أعطال متردده	1.32	0.36	3.68	3.43	0.41	1.41
19	تأخير إجراءات شراء المواد بواسطة المقاول الى ان يحين وقت تنفيذ النشاط	1.40	0.39	3.59	3.17	0.47	1.50
39	الإستعانه بآليات و معدات غير كفيه عدداً لإنجاز العمل خلال فترة العقد	1.34	0.39	3.45	3.09	0.48	1.47
24	قلة كميه مواد البناء التي يوردها المقاول الى المشروع حيث لا يتناسب حجم العمل المطلوب انجازه يوميا	1.37	0.40	3.41	2.78	0.50	1.38
12	قلة علوم و خبرة المقاولين من الباطن (عماله حرفيه ليس لها التزام العقود)	1.29	0.39	3.32	2.83	0.46	1.30
28	عدم توفير قطع غيار الآليات والمعدات أو التغير لصيانة الآليات والمعدات	1.54	0.48	3.23	2.96	0.43	1.46
30	سوء جودة مواد البناء التي يوردها المقاول الى المشروع بموقع المشروع	1.41	0.44	3.23	2.87	0.44	1.25
7	استعمال المقاول طريقة تنفيذ غير فعاله	1.54	0.50	3.09	3.09	0.45	1.38
1	نقص الأيدي العامله ذات المهارات المطلوبه حيث تكثر كسر وإعادة العمل	1.66	0.55	3.00	3.17	0.55	1.75
26	نقص الأيدي العامله ذات الإنتاجيه المطلوبه	1.66	0.57	2.95	3.00	0.41	1.24
5	قلة تحفيز العمل وليست لديهم رغبه حقيقيه للانجاز حسب معدلات الأداء	1.56	0.49	3.18	2.57	0.60	1.53
41	المقاول لا يتحدث مع صاحب العمل والمستشاري بأسلوب واضح	1.09	0.37	2.96	2.52	0.57	1.44
3	غياب الأيدي العامله عن العمل بدون سبب (absenteeism)	1.54	0.56	2.77	2.87	0.59	1.66
9	تأخير بدء العمل بالموقع بواسطة المقاول لأسباب مختلفه (حتى يكون المقاول مريح العمل بأسلوب	1.32	0.46	2.73	2.74	0.52	1.42

الجدول (9) ادناه يوضح الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان تكون افعال او اقوال المستشار سببا فى حدوثها رتبت ترتيبا تنازليا.

الجدول (9) الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان يكون الاستشارى سببا فى حدوثها

الرقم المتسلسل	الاسباب ذات الصله بتأخير تسليم مشاريع التشييد (المجموعة الثالثة)	الاستشاري			المقاول		
		الإنحراف المعياري	معامل التباين	متوسط الاهمية	متوسط الاهمية	معامل التباين	الإنحراف المعياري
16	تأخير في إصدار الأوامر التغيير بواسطة صاحب العمل	1.44	0.41	3.55	3.85	0.38	1.27
23	قلة علوم و خبرة ممثل الإستشاري في متابعة سير أداء العمل	1.21	0.40	3.05	3.17	0.46	1.47
17	قلة خبرة الإستشاري في تصميم وتأخير بكمية المستندات	1.41	0.44	3.23	2.83	0.51	1.44
4	الإستشاري لا يتحدث مع صاحب العمل والمقاول بأسلوب	1.45	0.53	2.73	2.70	0.48	1.29
25	قلة علم و خبرة الإستشاري في تخطيط وإدارة العقد	1.55	0.48	3.14	2.65	0.52	1.37

الجدول (10) ادناه يوضح الاسباب ذات الصله بتأخير اكمال مشاريع التشييد و التى يمكن ان تكون البيئة الخارجية سببا فى حدوثها رتبت ترتيبا تنازليا

الجدول (10)الاسباب ذات الصله بتأخير تسليم مشاريع التشييد و التى يمكن ان تكون البيئة الخارجية سببا فى حدوثها

التسلسل	الاسباب ذات الصله بتاخير تسليم مشاريع التشييد (المجموعة الثانية)	الاستشاري			المقاول		
		الانحراف المعياري	معامل التباين	متوسط الاهمية النسبية	معامل التباين	متوسط الاهمية النسبية	الانحراف المعياري
34	عوامل ذات صله بالصراعات المحلية او الحروب	1.27	0.32	4.00	0.46	3.39	1.56
21	عدم توفر المواد بالجوده المطلوبه بالسوق المحلي	1.49	0.45	3.27	0.36	3.35	1.19
40	زياده سعر المواد بالسوق المحلي (inflation)	1.58	0.50	3.14	0.54	3.30	1.77
15	عدم توفير قطع غيار بالسوق المحلي	1.67	0.51	3.27	0.41	3.26	1.32
36	عدم توفر المواد بالكميات المطلوبه بالسوق المحلي	1.48	0.49	3.00	0.42	3.26	1.36
11	تأخير توريد وتفليص المواد المستوردة من الجمارك	1.47	0.42	3.50	0.48	3.04	1.46
39	عوامل ذات صله بالتنظم واللوائح التي تطبقها الدوله	1.36	0.41	3.32	0.48	2.91	1.41
20	ارتفاع معدلات فوائد تمويل لمشاريع لاصحاب العمل	1.48	0.48	3.09	0.51	2.83	1.44
32	إضراب الايدي العامله عن العمل (strike)	1.83	0.64	2.86	0.66	2.61	1.73
2	بحالة الطقس (الرياح ،السيول ودرجات الحراره)	1.18	0.65	1.82	0.72	1.91	1.38

الجدول (11) ادناه يوضح الاسباب ذات الصله بتأخير تسليم مشاريع التشييد و التى يمكن ان يكون افعال او اقوال صاحب العمل سببا فى حدوثها رتبت ترتيبا تنازليا.

الجدول (11) الاسباب ذات الصله بتأخير تسليم مشاريع التشييد و التى يمكن ان يكون صاحب العمل سببا فى حدوثها

التسلسل	الاسباب ذات الصله بتاخير تسليم مشاريع التشييد (المجموعة الرابعة)	الاستشاري			المقاول		
		الانحراف المعياري	معامل التباين	متوسط الاهمية النسبية	معامل التباين	متوسط الاهمية النسبية	الانحراف المعياري
8	عدم دفع استحقاقات المقاول خلال الفتره المتوقعه	1.59	0.39	4.05	0.24	4.30	1.02
31	صاحب العمل قليل العلم و الخبره بمشاكل التشييد	1.44	0.41	3.55	0.38	3.43	1.31
37	بروز مشاكل بدراسة جدوى المشروع	1.24	0.38	3.27	0.47	3.22	1.51
42	الاختبار الاستشاري قليل الخبره والمعرفه	1.49	0.45	3.32	0.50	2.91	1.44
14	بطء في اتخاذ القرارات بواسطة صاحب العمل	1.13	0.34	3.32	0.55	2.87	1.58
33	بروز مشاكل مع جيران يمنع الوصول الى الموقع	1.32	0.42	3.14	0.57	2.83	1.61
6	تدخل صاحب العمل في مديرية فريق العمل	1.20	0.40	3.00	0.53	2.74	1.45
27	عدم تسليم الموقع للمقاول خاليا من الموانع	1.70	0.59	2.86	0.51	2.78	1.41
29	صاحب العمل لا يتصل مع الاستشاري او المقاول بأسلوب واضح	1.39	0.51	2.73	0.58	2.65	1.53

اخيرا، يلاحظ ان معرفة اسباب تأخير تسليم مشاريع التشييد يسهل عملية تحديد الطرف المخل من طرفى العقد. فالمقاول يتسبب فى احداث الاسباب الى تؤدى الى تأخير أكتمال المشروع بنسبة 55 % (اسباب الفئة الاولى) بينما يساهم كل من صاحب العمل و البيئة الخارجية ب (18 %) (اسباب الفئة الاولى)لكل منها ، اخيرا، يؤثر الاستشارى فى (9 %) من حدوث اسباب تاخير اكتمال المشاريع عن حينها(اسباب الفئة الاولى).

النتيجة اعلاه توضح اهمية ضبط سلوك المقاول وفق بنود العقد حيث انه يؤثر فى حدوث 55 % من اهم اسباب تاخير اكمال المشاريع عن حينها. فى حالة ظهور مشاكل مكلفة، لا غرو من اتهام المقاول بالقصور عن اداء واجباته اثناء التنفيذ قبيل تحليل بيانات و مستندات العقد لمعرفة ما حدث و استنتاج الطرف المخل. ايضا يلاحظ انه بناء على نظريات ادارة المشاريع، فان اى تغيير فى زمن المشروع يصطصحبه تغيير فى تكلفة المشروع او الاطار العام (او كليهما) .

5.الخلاصة و التوصيات:

1.5 الخلاصة:

1.1.5 كل اطراف العقد و البيئة الخارجية يمكن ان تساهم فى زيادة زمن المشروع (كل المجموعات الاربعة يمكن ان تساهم فى زيادة زمن المشروع و خلال اى من حقائب الفئات الثلاث)

2.1.5 اثناء تنفيذ المشروع، تؤثر افعال و اقوال طرفى العقد على معدلات انسياب مدخلات المشروع او التغيير فى الاطار العام (مع الاحتفاظ بمعدلات انسياب مدخلات المشروع) و تحدث تغييرا عن الخطة القاعدية فى زمن المشروع

3.1.5 بالرغم من معرفة عينة الاستشاريين و عينة المقاولين باسباب تاخير اكتمال المشاريع عن حينها و ترتيب الأسباب (32 سببا) و وضعها فى ذات الحقيبة الا ان تلك المعرفة لم تقلل تاخير اكمال المشاريع الى النسب المتوقعة

4.1.5 ان المقاول يساهم ب (55 %) من حدوث اسباب تاخير اكتمال المشاريع عن حينها بينما يساهم كل من صاحب العمل و البيئة الخارجية ب (18 %)لكل منها اخيرا، يؤثر الاستشارى ب (9 %) من حدوث اسباب تاخير اكتمال المشاريع عن حينها

5.1.5 اختلف متوسط عينة الاستشاريين و متوسط عينة المقاولين فى ترتيب 12 سببا و وضعوها فى حقائب مختلفة

6.1.5 ان اختلاف متوسط عينة الاستشاريين و متوسط عينة المقاولين فى ترتيب البندين 5 و البند 40 كبير (البند 40 الفئة الاولى و البند 5 الفئة الثالثة بواسطة المقاولون)

7.1.5 بناء على نتائج الدراسة، على مدراء المشاريع و اصحاب المشاريع و المقاولين و الاستشاريين العمل على ادارة اهم 26 % من الاسباب ذات الاهمية النسبية الاعلى لتأخير تسليم المشاريع و منع حدوثها حتى تكتمل المشاريع خلال المدة المحددة (الجدول ادناه):

رقم السبب	اهم 26%من الاسباب ذات الصله بتاخير تسليم مشاريع تشهيد عن حينها	متوسط الاهمية النسبية (الاستشارى)	متوسط الاهمية النسبية (المقاول)	المجموعة نسبية (المقاول و الفعال) (%)
8	عدم دفع مستحقات المقاول خلال الفترة المتوقعة	4.05	4.30	الرابعة (صاحب المشروع) (%18)
31	صاحب العمل قليل العلم و الخبره بمشاكل التشيد	3.55	3.43	
34	عوامل ذات صله بالصرعات العملية أو الحروب	4.00	3.39	الثانية (البيئة الخارجية للمشروع) (%18)
21	عدم توفر المواد بالجوده المطلوبه بالسوق المحلي	3.27	3.35	
16	تاخير فى إصدار الأوامر التغيير بواسطة صاحب العمل	3.55	3.35	الثالثة (الاستشارى) (%9)
35	صعوبات مالية يواجهها المقاول (قيمة المواد و استحقاق المقاولين من الباطن)	4.45	4.00	الاولى (المقاول) (%55)
19	تاخير اجراءات شراء المواد بواسطة المقاول التى أن يحين وقت تنفيذ النشاط	3.59	3.17	
18	ظاهرة المقاول أومبزه فى التخطيط وضبط الجوده	3.95	3.39	
22	استعانة المقاول بالباطن وعدلات قديما بتعطيل لخطة التوقيع على العقد	3.77	3.04	
10	ظاهرة المقاول فى تقدير تكلفة المشروع	3.73	3.17	
13	[illegible]	3.68	3.43	

2.5 **التوصيات:**

1.2.5 على الادارة العليا لشركات البناء والتشييد التاكد من التنافس فى العطاءات التى تناسب مقدرات شركاتهم المالية و الفنية

2.2.5 على الادارة العليا لشركات البناء والتشييد دراسة تكلفة وتامين التدفقات النقدية لاى مشروع و وذلك بالعمل سويا مع الاستشارى و صاحب العمل

3.2.5 على المكاتب والشركات الاستشارية العمل مع اصحاب العمل لانتاج مستندات عطاءات او مناقصات مكتملة حتى يتفادى فريق التنفيذ الاوامر التغييرية بقدر المستطاع

4.2.5 على الشركات الاستشارية و المقاولين تدوين سير تنفيذ المشروع لتسهيل حل مشكلات المشروع

5.2.5 على اطراف العقد مراقبة البيئة الخارجية للعقد من حيث الصراعات المحلية او الحروب ، مدى توفر المواد بالسوق ، التغيير فى اسعار المواد خلال فترة تنفيذ العقد

6.2.5 على صاحب العمل تامين تكلفة المشروع وفق التدفقات النقدية للمقاول ان اراد صاحب العمل تحقيق منافع المشروع الموضحة بدراسات الجدوى خلال العمر الانتاجى للمشروع

7.2.5 فى حالات الاقتصاد المتضخم ، نرى اضافة البند 40 (زياده سعر المواد بالسوق المحلي) الى حقيبة الفئة الاولى من الاسباب ليتم التخطيط لها و ادارتها بواسطة الادارة العليا

8.2.5 الالتزام بتفعيل بنود التعويض بالعقود الهندسية ليؤدى طرفا العقد مسؤلياتهم بفعالية و استعمال موارد الاطرف بكفاءة و فعالية

9.2.5 اهتمام المقاولون و الاستشاريون بالاتصال بينهما من خلال الاستفادة من علوم الاتصال وهذا يعتبر عصب نجاح اى مشروع ويضبط سلوك اطراف العقد وفق خطط العقدحيث يعتقد الباحث انها يجب ان تكون من اسباب الفئة الاولى

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considered reasonable alternative sources of aggregate for concrete asphalt mixture productions.

- Further research is still required to obtain new specifications for the use of SSA in different fields of application to conserve Sudan natural resources and preserve the environment.

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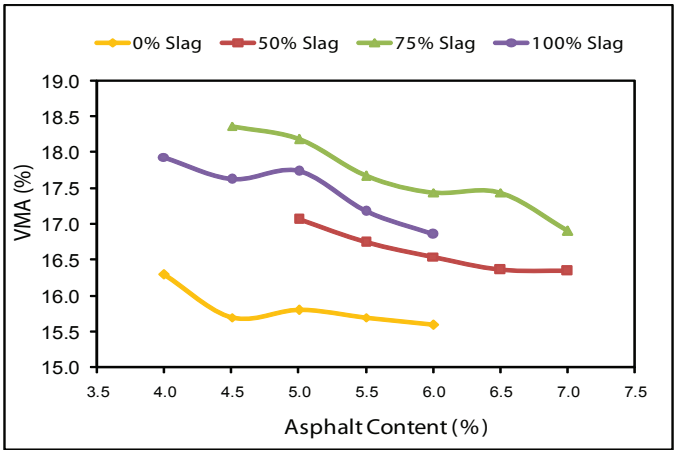

Fig. 6 Voids in mineral aggregate for different asphalt mixtures

4.Conclusion

In this research, natural aggregate was replaced by SSA, which is waste material derived from the steel industry, in different asphalt concrete mixes. The effectiveness of replacing natural aggregate by SSA was judged by the improvement in the physical and mechanical properties of the tested samples. The following conclusions can be drawn:

- The physical properties of SSA basically satisfy the requirements of Marshall Specification for design of HMA. Based on laboratory test results, SSA appears to be especially beneficial for the use in Sudan to reduce the dependent on naturally occurring aggregate. Thus, it is recommended that the producers and the users of AHM in Sudan consider the use of SSA.

- From the economic point of view, utilization of steel slag as road construction aggregate may reduce the cost of extracting and processing naturally occurring aggregates. The steel producing industry may also reduce their cost for treating and disposing the huge number of steel slag stockpiles.

- The use of natural aggregate in the HMA layer of road pavement is seen as a wasteful use of a finite natural resource. Therefore, the use of waste (secondary) materials is recognized as being of benefit to both environment and society. Of the various waste materials, the steel slag can be

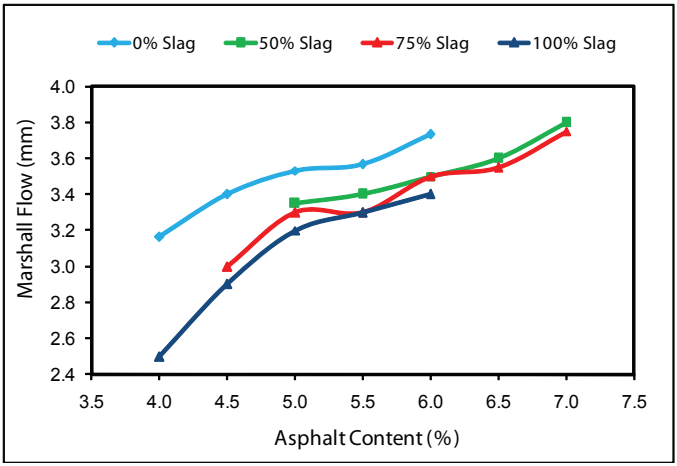

Fig. 4 Flow curves for different asphalt content and mixtures

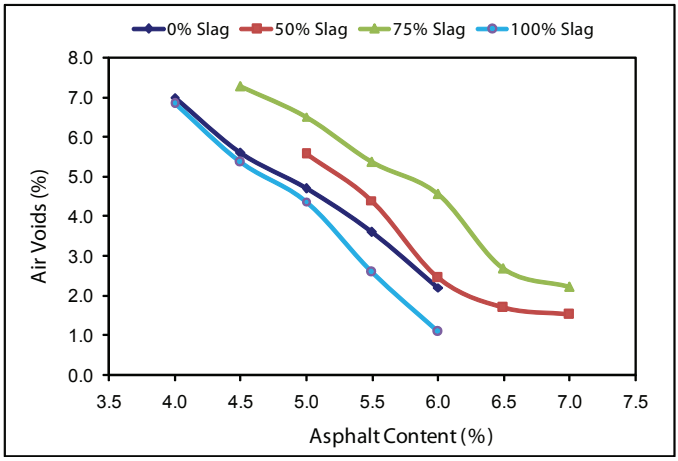

Fig. 5 Air voids versus asphalt content relationship for different asphalt mixtures

When stability and density values are considered, specimens prepared with SSA had the highest stability compared with the specimens prepared with natural aggregates, as shown in Fig. 3. It is believed that the reason for this is due to the low crushing and Los Angeles abrasion values of the (SSA) when compared to natural aggregates.

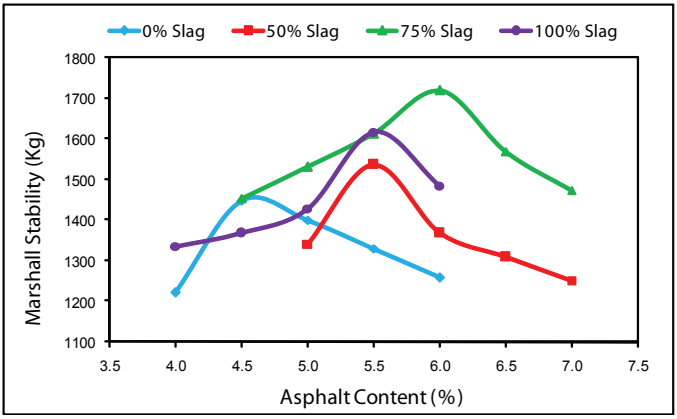

Fig. 3 Corrected stability curves for different asphalt mixtures

A slight decrease in the flow value was noticed in the case of specimens prepared with SSA when compared to the natural aggregate (NAG) specimens. The curves shown in Fig. 4 show that all specimens prepared at their optimum Asphalt Content (OAC) are in the range recommended by the Asphalt Institute between 3-5 mm for the surfacing and heavy traffic category ([15]). The Percentage of air voids (AV) decreased while VMA increased for specimens prepared with SSA when compared to the values of the NAG specimens as shown in Fig. 5 and 6, respectively. It seems that the particle shape, grading and maximum nominal size for the aggregate used play the major role in the determination of these values. It is important to mention that the AV and VMA values obtained for specimens prepared with SSA and NAG specimens comply with the values recommended by the Asphalt Institute [15].

The abrasion test provides an indication of the relative quality of competence of various sources of aggregate with similar mineral compositions. The abrasion test is used as an indication of aggregate wear resistance. In this case, comparing the steel slag aggregate results to the natural aggregate results illustrate that slag particles show high resistance to abrasion as given in Table 4. Also, the specific gravity values of the slag are always more than the natural aggregate.

Table 4 Physical and mechanical properties of aggregates

Test	Percent of SSA			
	0	*50*	*75*	*100*
Bulk specific gravity	*2.92*	*2.93*	*2.95*	*3.10*
Absorption,%	*2.3*	*2.6*	*2.7*	*3.2*
Los Angles abrasion, %	*14*	*12.0*	*11.5*	*10*
Flakiness, %	*22.1*	*14.0*	*11.2*	*8.4*
Elongation, %	*21.0*	*12.2*	*10.0*	*7.5*
Stripping & coating	*Above 95*			

The results of the mix design for both the SSA mix and the conventional natural aggregate mix are presented in Table 5. Comparing the results, it can be observed that steel slag aggregate provide better properties and high values of density and stability, which resist permanent deformation. The Marshall tests results on the prepared specimens showed that the Optimum Asphalt Content (OAC) was increased from a value of 5.1% in the case of specimens prepared with natural aggregate to a value of 6.1% for specimens prepared with 75% SSA. The reason is due to the high absorption value of the (SSA) used.

Table 5: Asphalt Hot Mix design results

Property	Percent of SSA			
	0	50	75	100
Optimum Asphalt Content, %	*5.1*	*5.6*	*6.1*	*5.3*
Max. Unit Weight, KN/m3	*24.0*	*23.9*	*24.0*	*24.0*
Marshall Stability, KN/m2	*1390*	*1530*	*1700*	*1560*
Flow, %	*3.5*	*3.4*	*3.5*	*3.2*
Air voids, %	*4.6*	*4.1*	*4.3*	*3.3*
VMA, %	*15.8*	*16.7*	*17.4*	*17.4*
VFB, %	*71*	*74*	*74*	*80*

3 . 3 Mix Design

For the evaluation of using SSA in asphalt mixes, Marshall specimens using natural aggregate were prepared at asphalt content 4, 4.5, 5, 5.5, 6% by weight of aggregate to be compared with those prepared with 50, 75 and 100% of SSA. Marshall Specimens were prepared and tested in accordance with ASTM D1559.

For all specimens, aggregate and asphalt were heated at temperatures of 140 and 180^{o}C, respectively. Specimens were compacted with 75 blows of Marshall's hammer on each side to count for heavy traffic category. Specimens were extracted from the molds and kept at ambient temperature for one day. Necessary data for obtaining the specific gravity, percentage of air voids (VA), voids filled with bitumen (VFB) and voids in Mineral Aggregates (VMA) and to count for stability correction were measured and recorded. These data are mainly the weight in air and water and the height of the specimens. To conduct the Marshall stability and flow tests, the specimens were kept in a water bath at 60^{o}C for 30 minutes. The Optimum Asphalt Content (OAC) values for the specimens prepared with different aggregate combinations were determined according to Marshall Stability, percentage of air voids and voids filled with bitumen.

3 . 4 Results and discussion

The results of the experiments conducted for measuring the physical properties of asphalt cement are listed in Table 3.

Table 3: Physical properties of asphalt cement used

Test	Method	Result
Penetration, 0.1mm	*ASTM D5*	*62*
Ductility, cm	*ASTM D113*	*100*
Softening Point, °C	*ASTM D36*	*58*
Kinematics viscosity, cst	*ASTM D2170*	*340*
Flash point, °C	*ASTM D92*	*250*
Fire point, °C	*ASTM D92*	*320*
Specific gravity	*ASTM D70*	*1.03*

The steel slag and natural aggregate samples were used to determine the physical and mechanical properties such as abrasion resistance, specific gravity, water absorption, flakiness and elongation, and stripping and coating. The tests results are shown in Table 4.

This aggregate was collected from the crushing plants at Toria hill.
Steel slag was delivered from the by-product of steel manufacturing at Giad factory in Khartoum. After the steel slag has been crushed and graded into the desired sizes it was stockpiled for delivery (Fig. 2). The surface texture of the slag was observed to be quite variable, from very dense and solid like basalt, to vesicular like volcanic cinders. SSA samples were selected from three different stockpiles of coarse aggregates, fine aggregates and mineral filler. The samples of SSA were delivered to the road laboratory at university of Khartoum.

Fig. 2 Stockpiling of steel slag aggregates at crushing plant

3 . 2 Sampling and Testing

The steel slag sample was subjected to crushing and screening into the desired sizes. Samples of steel slag and natural aggregates were prepared to three different sizes; the coarse sizes are 19 to 5 mm, the fine sizes passing sieve no. 4 (4.75mm) and retained on sieve no. 200 (0.075mm) and filler material of size finer than 0.075 mm.

A series of tests were carried out to determine the quality of asphalt used and the characteristics properties of SSA and natural aggregates. Laboratory tests conducted on aggregates include gradation, specific gravity and absorption, crushing value, Los Angeles abrasion test. Consistency tests performed on asphalt include penetration, ductility, softening point, kinematic viscosity and specific gravity test. Safety tests of flash and fired points were also conducted on asphalt. The tests were carried out in accordance with ASTM [14].

Due to its high levels of hardness and angularity, steel slag is able to improve skid resistance. Kehagia [18] carried out a study on the skid resistance of a thin wearing surface using three different mixes: 100% slag mix, partial slag replacement mix, and a natural aggregate mix. Skid resistance was measured four months and one year after installation on a high traffic highway in Greece. After one year, all the slag mixes had outperformed the natural aggregate mix. The mix with 100% slag exhibited the best skid resistance. The minimum allowable skid number on this type of roadway was 35. After one year of service, the value for the 100% slag mix section ranged from 58 to 64, whereas the section with partial slag replacement varied from 48 to 60. The natural aggregate section without steel slag displayed acceptable numbers from 40 to 57. The study showed that steel slag can improve HMA roadway conditions.

Based on the results of the previous studies reviewed, adding steel slag in HMA has significant improvement on the mechanical properties of the mix in terms of resistance to fatigue cracking, rutting and thermal cracking. Improvements in skid resistance also increase the safety of drivers on the roadway. The results indicated from the studies clearly show potential benefits of using SSA in HMA. However, due to climate and material variations, the use of steel slag in HMA must be investigated using local materials, based on local specifications. Therefore, the aim of this study is to investigate the effects of steel slag in HMA specifically for Sudan local materials and climate.

3 . Laboratory Testing

As the objective and purpose of this paper are to test the suitability of SSA for its application in the manufacture of asphalt mixtures, an intensive laboratory testing program was conducted. The tests were carried out to determine the characteristic properties of SSA and evaluate them in accordance with the standard specifications. It presents also the details regarding the proposed mix design for HMA that contains SSA. Then it describes in detail the tests of HMA that contains SSA and presents and analyzes the physical and mechanical property tests results.

3 . 1 Materials Used

The materials used in testing include asphalt, natural aggregate and steel slag aggregate. The asphalt used in preparing all specimens of penetration grade 60 - 70. This asphalt was obtained from asphalt plants belong to road contractors at Toria hill in Omdurman town.

The natural aggregate used in this study is crushed stones of different sizes.

Table 2: Mechanical properties of Steel Slag, [11]

Property	Value
Los Angeles abrasion (ASTM C131), %	*25 - 20*
Sodium sulfate soundness loss (ASTM C88), %	*12 >*
Angle of internal friction	*50° - 40°*
Hardness (measured by Moh's scale of mineral hardness)[1]	*7 - 6*
California bearing ratio (CBR), % top size 19 mm (3/4 inch)[2]	*Up to 300*

Note: 1. Hardness of dolomite measured on same scale is 3 to 4.
2. Typical CBR value for crushed limestone is 100%.

2 . 3 Previous Investigations

The use of steel slag in asphalt concrete has been investigated by many researchers. The previous studies have been conducted on HMA with varied percentage of SSA. Most of the studies were concerned about the utilization of steel slag in HMA as coarse aggregate replacement. The effects of steel slag on the performance of asphalt concrete are reviewed below.

United States have extensive experience with the addition of steel slag to HMA. Their experiences indicate that the addition of steel slag may enhance the performance characteristics of the pavement. In asphalt mixtures, the steel slag is usually added as part of the coarse aggregate fraction of the mixture at a percentage of 20% to 100%, depending on the application of the mixture. Since the slag is rough, the material improves the skid resistance of the pavement. Also, because of the high specific gravity and angular, interlocking features of the crushed steel slag, the resulting HMA is more stable and resistant to rutting ([14], [1], [15]).

Ahmedzade and Sengoz [16] evaluated the effect of steel slag in HMA with 100% coarse aggregate (limestone) replaced by SSA. They observed improved fatigue resistance as the steel slag mix exhibited higher indirect tensile strength and modulus values than the coarse aggregate mix. Pasetto and Baldo [17] conducted a study on steel slag in HMA by substituting the natural aggregate at 0%, 30%, 60%, and 90% SSA based on the total aggregate weight. The substitution included both coarse and fine aggregate particles. It was found that all the slag mixes exhibited better rutting resistance than the control mix under repeated axial loads. However, the 90% SSA mix performed better than all the other slag mixes.

Table I: Chemical composition of steel slag (source [13])

Constituent	Open Hearth Steel Slag	Basic Oxygen Steel Slag
Calcium oxide (CaO)	25.8	41.3
Silicon dioxide (SiO_2)	16.4	15.6
Iron (FeO or Fe_2O_3)	26.0	20.0
Magnesium oxide (MgO)	10.0	6.9
Manganese oxide (MnO)	11.2	8.9
Aluminum oxide (Al_2O_3)	2.4	2.2
Titanium dioxide (TiO_2)	0.8	0.5
Free lime (free CaO)	2.1	3.3

The chemical composition of steel slag varied with the steel making practice and the quality of steel being produced. However, in accordance with the description from FHWA [11], there were many grades of steel that can be produced, and the properties of the steel slag can change significantly with each grade. Grades of steel can be classified as high, medium, and low, depending on the carbon content of the steel. High-grade steels had high carbon content. To reduce the amount of carbon in the steel, greater oxygen levels were required in the steel-making process, [6].

2.2.3 Mechanical Properties

According to The Federal Highway Administration (FHWA) [11] the processed steel slag has favorable mechanical properties for use as aggregates in construction; these include good abrasion resistance, good soundness characteristics, and high bearing strength. These properties greatly improve the performance of asphalt mixes and road safety level. SSA exhibits less susceptibility to abrasion due to its high particle density, allowing it to provide better skid resistance than natural aggregate. Steel slag has a high degree of internal friction and high shear strength. FHWA [11] has documented the general mechanical properties of steel slag as given in Table 2.

2.2 Steel Slag Properties

Different properties of various aggregates influenced their level of performance and suitability for an application. The physical and mechanical characteristic of an aggregate played an important role in providing the ideal durability, permeability, stability and resistance against abrasion, cracking, and permanent deformation. Besides, the chemical composition of an aggregate was continuously studied and found to be a factor affecting its adhesion with other construction material to form an ideal combination. The National Slag Association (NSA) [10] along with the Federal Highway Administration (FHWA) [11] has documented some of the characteristics properties of steel slag.

2.2.1 Physical Properties:

Steel slag aggregates (SSA) are highly angular, roughly cubical pieces having flat or elongated shapes. They have rough vesicular nature with many non-interconnected cells which gives a greater surface area than natural aggregates of equal volume; this feature provides an excellent bond with bitumen, [10]. The rough textured surface of SSA provides the particle interlock, and if properly compacted, the high stability required for good serviceable pavements can be attained. Moreover SSA particle exhibits higher porosity, superior adhesion with binder due to its surface structure and chemical content, and favorable shapes. Pores continuity in SSA may improve the water permeability in asphalt mixes and improve the skid resistance, while the superior adhesion with bitumen may address the problem of stripping and moisture related damage on pavement. SSA has high bulk specific gravity and less than 3% water absorption. Also SSA exhibits high density, but apart from this feature most of the physical properties of steel slag are better than hard traditional rock aggregates.

GeoPave [12] pointed out that steel slag aggregates are strong and durable materials. They have excellent angular shape which helps to develop very strong interlocking properties. They have high resistance to abrasion and impact.

2.2.2 Chemical Properties

The chemical composition of steel slag is a complex matrix structure consisting primarily of simple oxides determined from elementary analysis of x-ray fluorescence. According to Emery [13], steel slag usually contains four major oxides, namely lime, magnesia, silica and alumina. Minor elements include sulfur, iron, manganese, alkalis and trace amount of several others. Table 1 shows the list of various ranges of compounds presents in steel slag as reported by Emery [13].

an angular, generally well-graded, material that is relatively free of metallic, and the recovered steel (2 to 4% of raw steel production) is a valuable scrap, [5]. There are several different types of steel slag produced during the manufacturing process, including furnace slag, raker slag, ladle slag, and cleanout or pit slag, [6]. Fig. 1 shows a diagram of the general flow and production of different slag in a modern steel plant.

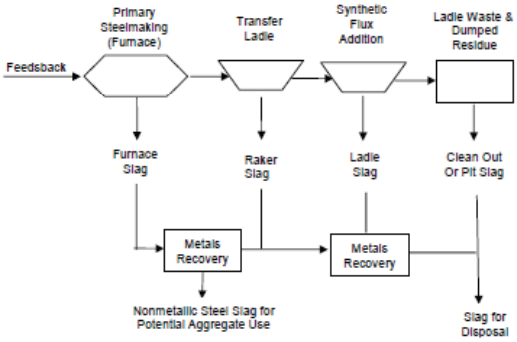

Fig. 1 Steel slag production in a modern integrated steel plant, [6]

In the past, the application of steel slag was not attractive because vast volumes of blast furnace slag were available. Steel slag has been used commercially since the mid-19th century. Recently, due to availability of electric-furnace steel throughout the world, also the growth of available amounts of this type of waste, steel slag is becoming increasingly important, while the application of steel slag is also rapidly growing in the developed countries, particularly in areas with high concentration of iron and steel production such as the United States, England, Japan and Canada.

Nowadays, extensive researches play a vital role to remove steel slag from industrial waste into modern industrial product which is effectively used for many industrial purposes, especially as raw material in road construction, [7], [8]. Special attention has been directed at investigating the possibilities of using it as substitute for natural mineral aggregates when producing asphalt mixtures. Even the old Romans used slag from furnaces in the construction of Roman roads in the Sussex District in England, [5]. Recently, the use of steel slag as an aggregate substitute to natural aggregates is considered a standard practice in many countries. In the USA slag is used from the first half of the 19th century as road construction material, from the second half of the 19th century as railway ballast and in cement industry, and from the beginning of the 20th century as aggregate for asphalt mixtures, [9].

1.Introduction

Steel slag has been used to construct pavements for nearly one hundred years. Since it was discovered that the residue from the manufacture of steel could be crushed and processed into a product that looked like crushed rock, researches were started to investigate the usefulness of this "waste" product. In Sudan, Giad factory in Khartoum produces significant quantities of steel-making slag as the major waste during the manufacture of iron and steel. The estimated daily production of steel slag is 15 – 20 tons. The disposal of steel slag in landfills may cause environmental hazards. The material produced by crushing and screening is the Steel Slag Aggregate (SSA).

In asphalt hot mixes (AHM), the physical and mechanical properties of the used aggregates play the major role in determining the overall properties of the mixtures. It is found that these required properties for AHM are found in the SSA, [1], [2]. The use of steel slag as an aggregate substitute to natural aggregates is considered a standard practice in many countries. The incorporation of steel slag as a AHM aggregate has been evaluated extensively in many parts of the world, but not yet in Sudan. In order to consider the use of SSA in Sudan, local materials, climate, and specifications must be taken into account. Therefore, it is imperative to carry out a comprehensive study, based on local materials and conditions, of the feasibility of utilizing the steel slag produced by steelmaking factory in Khartoum as a replacement for natural aggregate in production of asphalt concrete mixture.

2. Literature Review

2 .1 Steel Slag Production

Metallurgical slag is a waste or by-product formed in metallurgical processes from impurities in the metals or ores being treated. The metallurgical slags are classified in two types; ferrous and nonferrous slag. The ferrous slag includes iron slag generated in blast furnace process and steel slag produced from various processes (open hearth, basic oxygen and electric arc furnace). The nonferrous slag such as copper and nickel slag, [3]. The Steel slag is defined by Kalyoncu [4] as "a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel".

Processing of steel slag for steel recovery is very important as it results in

Experimental Study of Steel Slag Used As Aggregate in Asphalt Mixture

Magdi M.E. Zumrawi[1], Faiza O.A. Khalill[2]

Abstract

Steel slag is a by-product of the steel industry and can be used potentially as aggregate in asphalt mixture. This study evaluates the use of Steel Slag Aggregates (SSA) as substitute for natural aggregates in the production of hot mix asphalt (HMA) for road construction. Based on intensive laboratory testing program, the characteristic properties of SSA were assessed to determine its suitability to be used in HMA. Four different percentages (0, 50, 75 and 100%) of SSA were used, and the proposed mix designs for HMA were conducted in accordance with Marshall mix design. The experiments results revealed that the addition of SSA has significant improvement on the properties of HMA. An increase in density and stability and a reduction in flow and air voids values were clearly observed in specimens prepared with 100% SSA. It is concluded that the steel slag can be considered reasonable alternative source of aggregate for concrete asphalt mixture production.

Keywords : Aggregate, asphalt mixture, stability, steel slag.

مستخلص

إن خبث الحديد الصلب ناتج ثانوي لصناعة الحديد الصلب ويمكن استخدامه كركام خرساني في الخلطة الأسفلتية هذه الدراسة من أجل تقييم استخدام خبث الحديد الصلب كبديل للركام الخرساني الطبيعي في إنتاج الخلطة الاسفلتية الساخنة لتشييد الطرق بالإعتماد على برنامج إختبارات معملية مكثف تم تعيين الخواص المميزة لخبث الحديد الصلب لغرض تحديد مدى إمكانية إستخدامه في الخلطة الأسفلتية الساخنة . أستخدمت أربعة نسب مختلفة (100,75,50,0 %) من خبث الحديد الصلب لتصميم خلطات أسفلتية وفقاً لطريقة مارشال التصميمية.

نتائج التجارب أوضحت أن اضافة خبث الحديد الصلب عمل علىتحسين كبير في خواص الخلطة الأسفلتية الساخنة. وقد تلاحظ زيادة في الكثافة والثبات وإنخفاض في قيم الانسياب ونسبة فراغات الهواء وذلك بشكل واضح في عينات أعدت بإضافة خبث الحديد الصلب بنسبة 100 % يستنتج من ذلك أن خبث الحديد الصلب يمكن إعتباره مصدر بديل مناسب للركام الخرساني لإنتاج الخلطة الأسفلتية.

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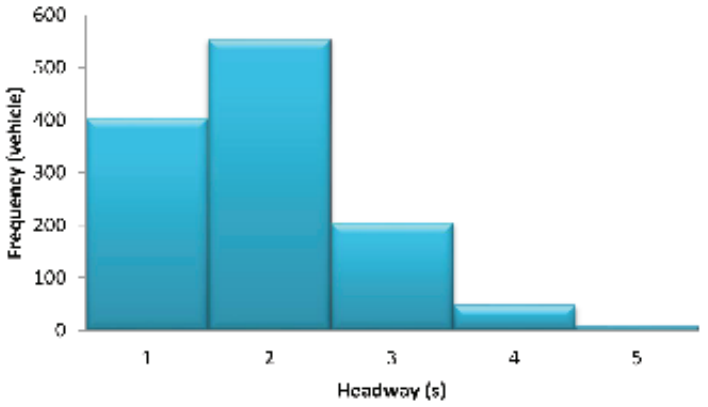

Fig 9: Frequency Distribution of Follow up Headway

5. Conclusion

To sum up the mean critical gap value were found 3.64s with upper bound of 3.68s and lower bound 3.60s, the standard deviation of the critical gap is 0.67s by using Wu model. The critical gap value using Raff's method was found 3.5s.The two methods almost give the same result for the critical gap.

The mean follow up headway was found at 1.94s with upper bound 1.99s and lower bound 1.89s, the standard deviation of follow up headway is 0.85s.

TRB [2] mention that the lower bound for critical gap is 4.1s and for upper bound is 4.6s. The follow up headway is 2.6s for lower bound and 3.1s for upper bound.

By comparing the values of the critical gap and follow up headway with those values of TRB [2] the lower value indicate that the drivers have limited experiences in using roundabout, they are tended to be more aggressive.The study recommended further research on critical gap and follow up headway in Malaysia using different roundabouts types. Moreover conducting educational/awareness campaign for drivers and enforcement on the operation in the use of roundabouts.

Table 1: Critical gap macroscopic probability of equilibrium model

Critical Gap (s)	Standard Deviation	Confidence level 95%	
		Upper Bound	Lower Bound
3.64	0.64	3.68	3.60

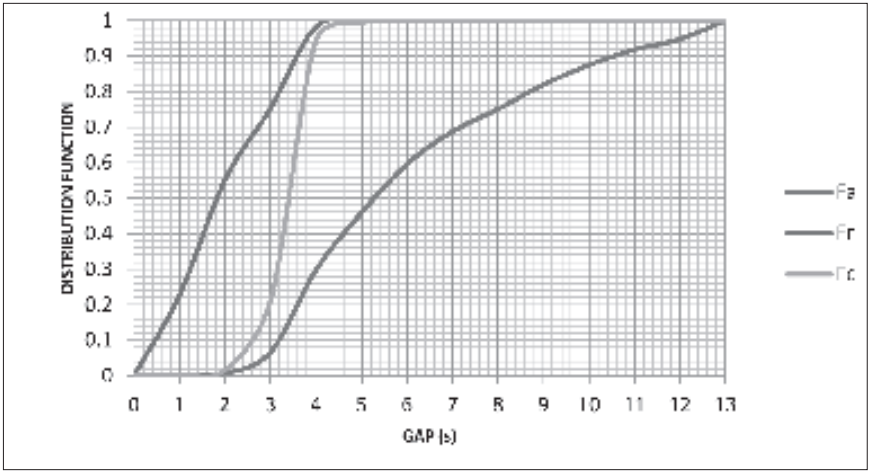

Fig 8: Critical gap macroscopic probability of equilibrium model

The follow-up headway was obtained directly from recorded time events. By definition, follow up headway is the minimum headway between two entering vehicles, which can be calculated by the average difference between the passage times of two entering vehicles accepting the same main stream headway under a queued condition. Table 2 shows the result of follow up headway and standard deviation. From the table it was found that the follow up headway is 1.94s and the standard deviation equal to 0.85s. Figure 9 shows the frequency distribution for the follow-up headway

Table 2: Follow up headway

Follow up Headway (s)	Standard Deviation (s)	Confidence level 95%	
		Upper Bound	Lower Bound
1.94	0.85	1.99	1.89

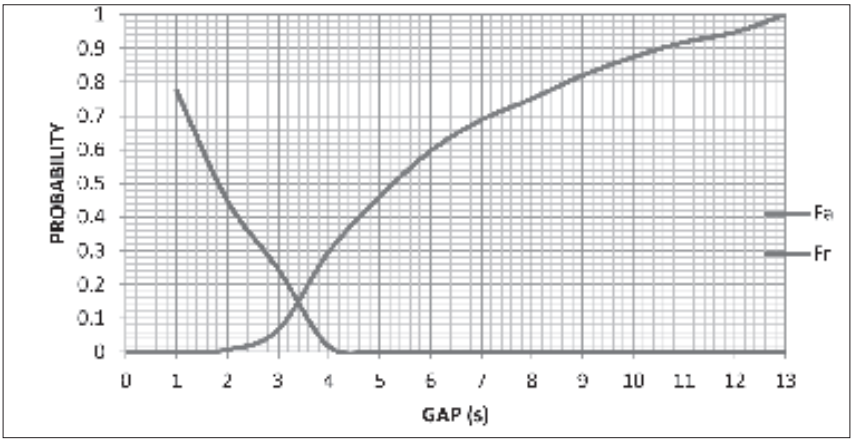

Fig7: Critical gap Raff's model

The distribution functions of probability of accepted gaps *Fa (t)* and rejected gaps *Fr (t)* are shown on Figure 8. The distribution function of critical gap *Ftc(t)* was calculated in accordance with macroscopic probability equilibrium model of Wu and the curve of this function lies between *Fa (t)* and *Fr (t)*. The mean value of the critical gap *tc = 3.64* s with standard deviation 0.67s. All the results were listed in Table 1.

After calculating the mean and standard deviation of critical gap and follow up headway of sample of population (sample size = 1340) it is important to estimate the confidence band for the population mean based on the sample mean using 95-percent confidence level (α=0.05) to estimate the upper and lower bounds of respective means as illustrated by Equation [4].

$$\bar{\mu}_i = \bar{y}_i \pm t_{\left(\frac{\alpha}{2},df\right)}\left[\frac{s_i}{\sqrt{n_i}}\right] \quad [4]$$

Where

- $\bar{\mu}_i$: Upper or lower bound of natural of logarithms of population mean
- $\bar{y}_i$: Sample mean
- s_i : Standard deviation
- $t_{\left(\frac{\alpha}{2},df\right)}$: t- Distribution value cross pounding to the degree of freedom Alfa value equal to 1.96 for 95% confidence level and degree of freedom greater than 100
  - d_f : degrees of freedom (n-1)
  - n_i : sample size

both entry traffic for the four approaches of the roundabout and circulating traffic for at least one hour, during morning peak hour and afternoon peak hour for three days.The cameras were placed at a high ground point level to ease the observation of the gaps as shown in Figure [6]

Fig 6: The camera position at the roundabout

4 . Results and Discussion

Data was collected by video recording with a camcorder. The camcorder was positioned at an approach to capture both entry traffic for the four approaches of the roundabout and circulating traffic for at least two hours a day, during morning peak hour and afternoon peak hour for three days. After that the data transferred to a computer and reduced by reading vehicle positions past common conflict area into MS Excel, the rear bumper was used as a common vehicle reference since it gave a complete vehicle clearance past a common conflict point.

The critical gap was estimated at the entry of the roundabout, using two different methods Raff's model and macroscopic probability of equilibrium model.

Figure7 shows the result of critical gap that were obtained from Raff method. The curves of accumulative probability of accepted gaps *Fa (t)* and rejected gaps *Fr (t)* were drawn. The critical gap is at the cross point of *Fa (t)* and *1–Fr(t)* was taken. The critical gap was found *3.5s*.

The difference between Raff's model and Wu model, Raff's model is extremely simple and easy to understand, beside this there is no iterative calculation required. On the other hand the model based on the macroscopic probability equilibrium of Wu (2006) has the following advantages:

a. The possibility of achieving the empirical probability distribution function of the critical gaps directly,
b. Simple calculation procedure without iteration,
c. Solid theoretical background (equilibrium of probabilities),
d. Robust results,
e. Independent of any model assumptions,
f. The possibility of taking into account all relevant gaps (not only the maximum rejected gaps as is the case of the (Troutbeck model (1992))

3 . Experimental Work

The scope of this study has only focused on the driver merging gap acceptance at a roundabout. For this, purpose traffic data was collected to find the critical gap and the follow up headway, which presented the major parameter for the gap acceptance principle. The critical gap was estimated using Raff's model and macroscopic probability of equilibrium model. The follow up headway was obtained directly from the recorded time events.

3 . 1 Data collection Method

The data collection method on this study includes the following:

a) Site Investigation

The selected site must have good access and safety for the researchers and equipment during the process of data collection. Meanwhile, the traffic volume must be high enough so as to ensure the data collected is adequate to be analysed. The site should also have a good sight distance location for video recording purposes. It was very hard to find a roundabout match all the above criteria, due to little number of roundabouts in Skudai area. After searching for roundabout that met all selection criteria the choice fell on university technology Malaysia roundabout(UTM). UTM roundabout belongs to the category of small two lane roundabout. The roundabout faces heavy traffic stream at morning peak and as same as at afternoon peak.

b) Actual field data collection

The methodology used in the data collection was mainly by video recording with a camcorder. The camcorder was positioned at an approach to capture

tion, Wu's method is based on the following probability equilibrium Equation [2].

$$Pr,tc = Fr(t).Pr,tc + Fa(t).Pa,tc \qquad [2]$$

Denote the distribution function of the critical gaps to be estimated by *Ftc (t)*, then the probability *Pr,tc (t)* that a gap of length t in the major stream would be rejected is *Ftc (t)*, and the probability that it would be accepted is *1–Ftc (t)*. Substituting *Pr,tc (t) = Ftc (t)* and *Pa,tc (t) = 1–Ftc (t)*, for Wu´s model the following distribution function *Ftc (t)* of the critical gaps present in Equation [3]:

$$Ftc(t) = \frac{Fa(t)}{Fa(t)+1-Fr(t)} = 1 - \frac{1-Fr(t)}{Fa(t)+1-Fr(t)} \qquad [3]$$

Wu proved that Equation [3] means that the result from Raff's model is the median value but not the mean value of the critical gap [12].

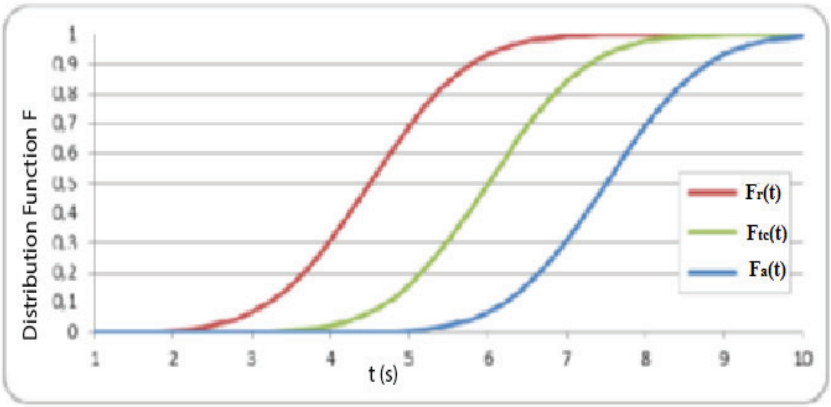

Fig 5: Schematic relationship between the PDF's for the rejected gaps, the accepted gaps, and the estimated critical gaps from the Wu model.

A comparison between the Raff's methods, Maximum likelihood of Troutbeck and the macroscopic method of Wu had been made, and it was found that the macroscopic method of Wu gives similar results for the mean critical gaps as that from recognized MLM of Troutbeck [7].In addition, one can get not only the main value of critical gaps but also the median value, which is the same value as the result of Raff´s method [7]. Also one can directly get the probability distribution function ofthe critical gaps [7]. Advantage of this method is simple calculation procedure without iteration as it is in the case of the Troutbeck model [7].

2.2.3 Maximum Likelihood

The maximum likelihood method of estimating critical gap is based on the fact that a driver's critical gap is a value between the range of his largest rejected gap and his accepted gap. A probabilistic distribution for the critical gaps must be assumed, a log-normal distribution for the critical gaps had been used [9]. This distribution is skewed to the right and has non-negative values, as would be expected in these circumstances. In this model, two assumptions are made:

a. A log-normal distribution of the critical gaps and
b. The driver behaviour is both homogeneous and consistent

An assessment of varied models using microscopic simulation had been made [10], and found that the model of Troutbeck gives the best results. Thus, this model is recommended for estimating the critical gaps in many standard manuals for traffic engineering (e.g., TRB 2000, HBS 2001, etc.). The maximum likelihood model was used to analysis critical gap of dual lane roundabouts [11], and the results show that the critical gap depends, among other factors, on the target lane (near or far), and the type of the vehicle. A population of drivers has variable critical gaps and this variability can be explained by a probability distribution. The above statements point to the fact that critical gap varies across drivers in a population and amongst individual drivers [6].

2.2.4 The Macroscopic Probability Equilibrium Model

Wu [12] suggested with a new model for estimating critical gap and its distribution at un-signalised intersection based on the equilibrium of probabilities, his claim that the assumption of Troutbeck are disadvantages. Furthermore, the model of Troutbeck is very complicated to use and its results are not very robust [12]. This model also requires a large sample size for establishing stable results [12]. He noted that the equilibrium of probabilities lies between the largest rejected and smallest accepted gaps for a population of drivers as shown in Figure 5 [12].

The theoretical background of the Wu´s model is based on the probability equilibrium between the rejected and the accepted gaps. The cumulative distribution of the rejected and accepted gaps is used to establish the macroscopic probability equilibrium. The observed probability that a gap of length t is accepted is *Fa (t)* and that it is not-accepted is *1–Fa (t)*. The observed probability that a gap of length t is rejected is *Fr (t)* and that it is not-rejected is *1–Fr (t)*. Generally *Fr (t)*is not equal *1–Fa (t)* and also *1–Fr (t)*is not equal *Fa (t)*. Considering the observed probability of both acceptance and rejec-

2.2 Gap Acceptance Models

Estimation of gap acceptance parameter from traffic observation is a very difficult task for traffic engineers. Critical gap need statistical models or procedure to estimate. Many models have been developed to estimate the critical gap.

2.2.1 Raff's Model

Raff model had been used in many countries in the past; because of it is simple and easy to understand. Equation (1) represent Raff's model [7]; the model is based on the probability distribution function (PDFs). Let *Fr (t)* and *Fa (t)* be the probability distribution functions (PDFs) of rejected and accepted gaps, respectively. Then *Fr (t)* and *Fa (t)* can be obtained empirically by in situ measurements. Thus, the observed probability that a gap of length t is rejected is *Fr (t)*, and that it is not rejected is *1-Fr (t)*.

Raff's model defines the critical gap as the value of t where the functions *1-Fr(t)* and *Fa (t)* intercept as described in Figure 4:

$$Fa(t) = 1 - Fr(t) \qquad (1)$$

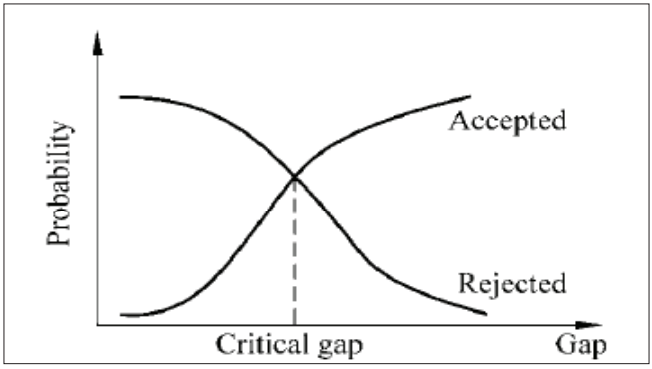

Fig 4:Critical Gap by Raff's model

2.2.2 Ashton's Model

Ashton model is a modification to Raff's model by using of both lags and gaps [8]. The numbers of rejected lags and gaps of all sizes have been scaled so that the total number of rejected lags and gaps equals the total number of accepted lags and gaps. The asymptotic value for Ashton's critical lag is derived as the solution of complex integral equations involving both the distribution of minimum acceptable gaps and the distribution of offered gaps.

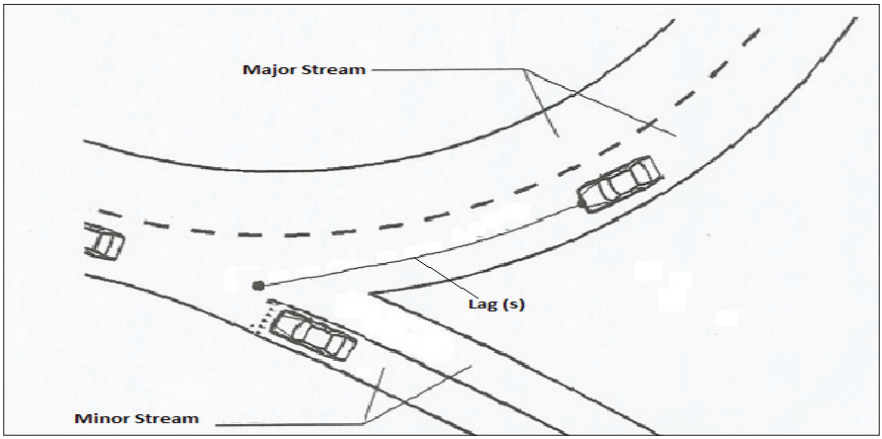

Fig 2: Lag and Gap Definition

Follow up headway is defined as the time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same major street gap as shown in Figure 3.

The follow-up headway at single-lane roundabouts is related to the roundabout size (inscribed circle diameter) and circulating flow rate [3]. Higher circulating flow rate resulted in much smaller follow-up headway.

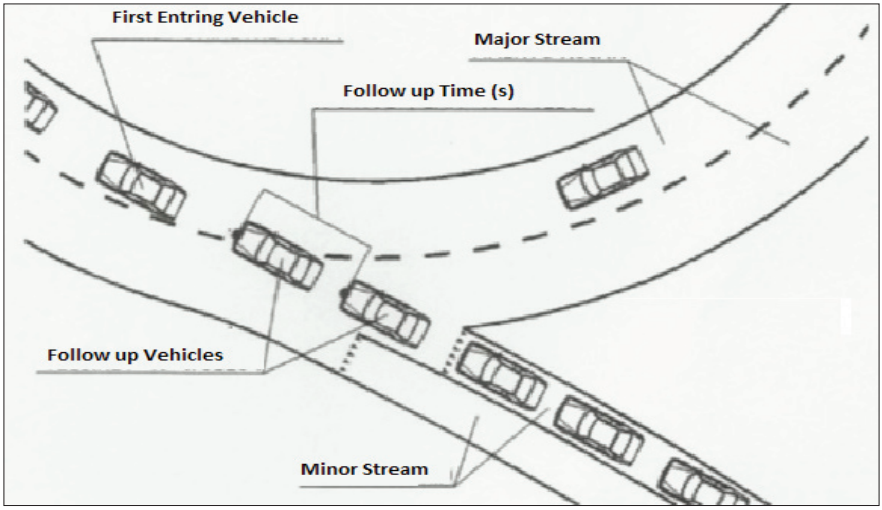

Fig 3: Follows up Headway

A gap acceptance theory is a more appropriate tool in estimating the capacity of the roundabout. An advantage of this method is that the gap acceptance technique offers a logical basis for the evaluation of capacity [5]. Secondly, it is easy to appreciate the meaning of the parameters used and to make adjustments for unusual conditions [5]. Moreover gap acceptance conceptually relates traffic interactions at roundabouts with the availability of gap in the traffic streams [5].

There is variety of gap acceptance application in transportation engineering due to the operational characteristics of traffic streams within the road system. There are three major applications [6] i.e.:

a. Freeway merges from ramp to main freeway,
b. Lane changes in multi-lane highways, and
c. Freeways, un-signalized intersections, roundabouts and permitted right-turn phase at signalized intersections for countries that use keep left driving rule on the road.

A critical gap is defined as the minimum time interval in the major street traffic stream that allows intersection entry for a minor street vehicle [2]. A particular driver would reject any gap less than the critical gap and would accept a gap greater or equal to the critical gap. Estimates of critical gap can be made on the basis of observation of the largest rejected and smallest accepted for a given intersection

The rejected gap is defined as the time interval that a subject vehicle fails to enter a main lane due to the vehicle obstacle flow in the main lane. “Maximum rejected gap” is the largest rejected gap in the middle of the reject gaps of the individual vehicles [2].

Accepted gap is defined as the time interval for a subject vehicle in the current lane to enter the traffic stream on the main lane without vehicle obstacle flow from the main lane as illustrated by Figure 2 [2]. The general assumption is that drivers only consider the adjacent gap i.e. the headway between a lead vehicle and a lag vehicle over the object lane to which it wishes to change to. In the case of merging into the adjacent lane, if the driver can accept both lead and lag headway, the gap is accepted and the lane changing is accomplished.

2 . Literature Review

The roundabout has the ability to decrease the number of the conflicts point in the intersection as shown in Figure 1. The conflict points are reduced from 32 points to just 8 points. Four points are diverging conflict and the other four are merging conflicts. The crossing conflicts are eliminated by the roundabout.

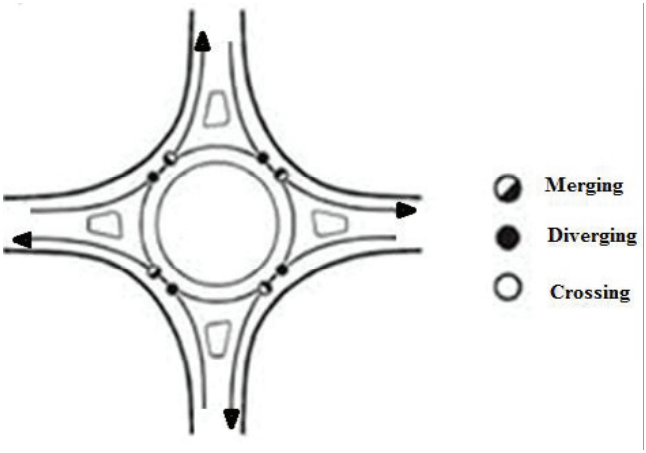

Fig 1: Potential collision points at roundabout

Studies by the Federal Highway Authority and Insurance Institute for Highway Safety (IIHS) have shown that roundabouts typically achieve[4]:

- 37% reduction in overall collisions
- 75% reduction in injury collisions
- 90 % reduction in fatality collisions
- 40% reduction in pedestrian collisions
- 75 % fewer conflict points than a traditional intersection

2 . 1 Gap Acceptance Concept

At un-signalized intersection driver should make a certain decision when it is safe to cross or merge into the conflicts traffic flow. The need to search for gaps between vehicles that they can accept, take into their account other driver have higher priority (yield and stop control). This method is known as gap acceptance method.

عدوانية في دخول الدوار، و لديهم معرفة محدودة عن إستخدام قواعد الدوار. الذي يؤدي إلى التصادم الوشيك والازدحام.

1 . Introduction

Roundabouts are a type of intersection. Roundabouts are becoming increasingly popular because of their performance in terms of safety, capacity, and cost. Roundabouts have the potential to reduce accident risk, since the traffic flows merge and diverge at small angles and low speeds. Under certain conditions, roundabouts also improve the flow of traffic at the intersection, compared to other choices. Usually the circulating vehicles have priority of movement and all entering vehicles must reject or accept the available gaps while waiting to enter [1]. As traffic volumes increase on local roadways, engineers are more frequently turning to roundabouts as an efficient, cost-effective way to improve safety and traffic flow. Roundabouts substantially decrease severe injury and fatality collisions and allow drivers to get through intersections more quickly. Roundabouts also provide a safer way for pedestrians and bicyclists to navigate traffic.

1 . 1 Research Problem

The roundabout entry capacity is one of the major issues for the traffic engineer. The entry capacity is suggested to be an exponential function that depends on the critical gap and follow up headway [2].

The critical gap plays an important role in order to determine the need for stop signs and to solve other design problems at any intersection. The availability of quantitate data for the critical gap charteristics therefore is very important for this application [3].

1 . 2 Aim and Objectives

The aim of this study is to estimate the driver merging gap acceptance at the roundabout. To achieve this aim, the study was carried out based on the following objectives:

I. To collect and analysis gap acceptance and rejection data at roundabout

II. To determine driver's critical gap and follow up headway time at a roundabout using two different methods

Driver's Merging Gap Acceptance at Roundabout

Shaza Farouk Azhari Hassan[1]

Abstract

Roundabouts in many cities around the world are becoming more popular to use in their roads rather than other types of intersections. The roundabout entry capacity is one of the major issues for the traffic engineer. The principle of gap acceptance is the main principle for calculating the capacity of a roundabout, using critical gap and follow up headway as key parameters. This paper presents the findings of estimation of the critical gap and follow-up headway in Malaysia roundabouts; roundabout at University Technology Malaysia was chosen as a case study. Research data was collected using video technology and reduced by recording time positions of vehicles into MS Excel. Accepted and rejected gaps of individual entry drivers were obtained. Raff's method and the model based on the macroscopic probability equilibrium were used to estimate the critical gap from a pair of accepted and rejected gaps of individual drivers. The follow-up headway was obtained directly from recorded time events. The results of the critical gap show that the two methods gave almost the same results. Comparing the results with that at TRB (2000) the lower values indicate that the drivers tended to be more aggressive in entering the roundabout and have limited knowledge of use of roundabout rules. That leads to near misses and congestion.

مستخلص:

الدوارات في العديد من المدن في مختلف أنحاء العالم أصبحت أكثر شعبية لاستخدامها في الطرق بدلا من الأنواع الأخرى من التقاطعات. سعة دخول الدوار هي واحدة من القضايا الكبرى لمهندس المرور. مبدأ قبول الفجوة هو المبدأ الرئيسي لحساب سعة الدوار، وذلك باستخدام الفجوة الحرجة ومتابعة التقدم كمعاملات أساسية. تعرض هذه الورقة نتائج تقدير الفجوة الحرجة ومتابعة التقدم في الدوارات فى ماليزيا. وقد تم اختيار دوار في جامعة التكنولوجيا الماليزية كحالة دراسة. وقد تم جمع بيانات البحث باستخدام تكنولوجيا الفيديو وخفضت من خلال تسجيل زمن مواقع المركبات في مايكروسوفت إكسل. وقد تم الحصول على الفجوات المقبولة والمرفوضة من دخول أى سائق. استخدمت طريقة راف والنموذج القائم على احتمال التوازن العياني لتقدير الفجوة الحرجة من زوج من الفجوات المقبولة والمرفوضة لأى سائق. تم الحصول على متابعة التقدم مباشرة من الأحداث الزمنية المسجلة. نتائج الفجوة الحرجة تدل على أن الطريقتين تعطيان نتائج متقاربة. مقارنة هذه النتائج مع نتائج(TRB 2000) هذه القيم المنخفضة تشير إلى أن السائقين يميلون إلى أن يكونوا أكثر

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signed for this specific task; they carried out the study and supervised the rehabilitation works. The authors are grateful to the UKCC administration for giving permission to use the project data. Also the efforts of the Resident Engineer (Mohamed A/Al-Raoof),Messers"Hassan Al-Musharraf for Trade and Construction Company Limited"and their projects manger (Eng. Mohamed A/Al-Karim) and are highly valued for their team work cooperation in completing the rehabilitation works satisfactorily and within the specified time span.

10. References.

[1] Y.T.Mosa and O.A.Abdalla "Structural Assessment for roof the main pump House at Study at Assalya Sugar Factory " UKKCC, Khartoum June 2014.

[2] 2. BS 5950-2000- Structural use of steel in building.

[3] 3. BS ISO 16172:2011- Continuous hot- dip metallic coated steel sheets.

[4] Y.T.Mousa and O.A.Abdalla " Inception and progress Reports for the Rehabilitation of the roof of the main Pump House at Aaaalaya Sugar Factory" UKKCC , Khartoum June – August 2015.

[5] Y.T.Musa and O.A.Abdalla " Substantial Completion Report for the rehabilitation of the roof of the main Pump house at Assalaya Sugar Factory , UKCC ,Khartoum ,Sudan , September 2015.

7. Post demolition findings.

During the demolition operations [4] the following remarks were noted:

- the roof slab was cast thicker than it's specified thickness - it exceeds 0.25 m in many locations (instead of 0.15 m - thus adding overburden loads to the roof, [see plates no. 11]. .

- the roof slab was lightly / under reinforced (T10@250c/c B/W) as compared to its span length and the applied loads [see plates no. 12]. . .

- the main beams were having x-sectional area of 0.30*0.5m and were also lightly /under reinforced (5T16 bottom and 3T16 top)as compared to its span and the supported loads.

- the reinforcement bars recovered from the demolished roof system were found undistorted indicating to the fact that concrete of the roof was of low grade quality.

-short pieces of reinforcement bars, slags .etc. were found thrown in the roof slab.

8. Conclusions.

-the innovative method adopted enabled rehabilitation of the roof of the MPS at ASF in a short time and at a relatively low cost, thus saving the Factory from the disastrous effects which might have occurred if not being done.[5]

- rehabilitation of industrial buildings, which were built in last decades inherit some design and construction problems,and need smart handling in order to prolong its life span and avoid any possible failures or malfunctioning.

- rehabilitation of these types of structures needs qualified and experienced personnel and firms to do such jobs.

- utmost safety precautionary measures are needed in such works.

9. Acknowledgement.

This work was part of the UKCC consultancy services conducted, at first on July 2014 for the structural assessment study and second during the period between April to August 2015. The authors were structural consultants as-

All drawings and design calculations were revised according to the submitted specifications and conceptual designs.

By adopting and following the described method, the rehabilitation works [plate 10] were carried out & completed professionally, safely, efficiently, in a very short period (four months) and with a reasonable cost (only 174,000.00 USD).

Plate No. (6): Steel Truss ready for painting & lifting.

Plate No. (7): Steel Truss fixed to position together with purlins.

Plate No. (8): Roof Sheeting's fixed on trusses.

Plate No. (9): Complete CMS roof after removal of the overhead platform.

Plate No. (10): Side View of CMS roof upon completion.

cording to the given specifications and the conceptual designs & drawings, were prepared, as outlined below:

A. Overhead Platform

The overhead platform is composed from the following components:

- Boxlattice main girders (x-sectional area 0.4*0.6m) assembled from rectangular hollow sections pipes chords (top &bottom),verticals& diagonals - to span the distance between the RC crane beams (8.6m apart) at spacing of 2.0m c/c along the crane beams. These girders are firmly fixed/tied to the existing RC crane beams [Fig 5 & plates no. 1, 2, 3, 4&5]. .

- Purlins from rectangular hollow section pipes spaced @ 1.0m c/c, fixed and tied to lattice box girders [plates 3 &4]. .

- Plywood plates, 20 mm thick, laid on & riveted to the purlins [plate 5]. .

- Polythene sheets laid on the plywood plates.

- Curtain wall, made from rectangular hollow sections pipes and ployethene sheets, to extend vertically from edge of the platform to the concrete roof.

- External scaffolding around the MPS.

- Temporary mobile steel ladder made from rectangular hollow sections pipes.

- Barrel pipe down shoot for removal of debris.

B. Roof trusses

- Trusses (Howe Truss type) assembled according to 5950-2000[2], by welding from rectangular hollow section pipes [plates 6, 7, 8 & 9].

- Purlins from rectangular hollow section pipes.

- Bracings from rectangular hollow section pipes.

- Stiffening the bottom chord at the end joint of the roof truss, bearing plate and anchor bolts.

- Corrugated metal sheets gauge 24 complying with B5 15016172:2011[3] was used.

Plate (1): Assembly of Lattice Box Girders.

Plate (2): Lattice Box Girders ready for lifting.

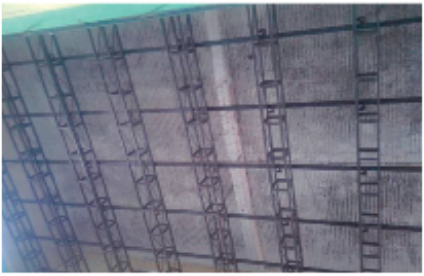

Plate (3): Lattice Box Girders lift to position, with purlins fixed on it just below the defected concrete roof.

Plate (4): View of overhead platform from beneath.

Plate (5): View of overhead platform from above

6. Rehabilitation works.

The construction Contractor "Hassan Al-Musharraf for Trade and Construction Company Limited" was entrusted by the Sudanese Sugar Co. Ltd. to carryout the required works under the supervision of UKCC.

The detailed designs and drawings for the platform and the roof trusses, ac-

the pump/groundfloor level. The overhead platform to be designed rigid and strong enough to support safely it's own weight, the load of debris from demolished RC, the new corrugated metal roof materials, the personnel involved in rehabilitation works and their necessary tools.

- Demolition of the whole concrete roof system (except the top tie beam), and the top of column's heads to be carried out using light hand tools.

- Design, assembly and erection of a complete light roof (corrugated metal sheets roof).

- Cleaning and painting the inner walls of the MPS and control room, carting away debris and cleaning the site of works and restoration of the MPS to its original working conditions.

The overhead platform is comprised of main lattice girders assembled from rectangular steel hollow sections [Fig. (5) & plates (1) & (2)] ,rectangular steel hollow sections purlins and plywood plates. The platform was covered by ployethene sheets to safeguard against the dust -resulting from demolition activities - from entering the MPS [Fig. (3) & plates 3, 4 &5].

After due consultations with the administration of irrigation sector at ASF, it was agreed to reschedule the pumping operations at MPS by shutting down half of the pumps & covering / warping them by ployethene sheets, during the whole period of rehabilitation works of that half of the MPS roof.

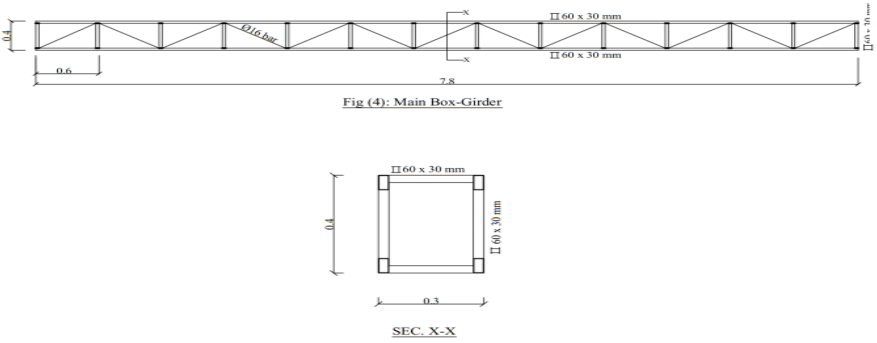

Fig (5): Main lattice Box Girder

5. Remedial Methodology.

The main concerns of the Client (Owner), as mentioned above, were:

I. Safe guard against any sudden failure of the RC roof.

II. Remedial method adopted shall not interrupt the operation schedule of the pumps in MPH and shall guarantee the safety of the equipments &personnel at the MPS.

III. Remedial works are to be completed in short reasonable period of time.

The team of experts studied all possible options for the rehabilitation works under these constrained and challenging conditions and concluded that the first obvious thinking of carrying the remedial works from the ground floor level was not seen feasible &acceptable; instead it was thought wise to confine all the rehabilitation works (inside the MPS) above the level of the RC crane beams at height of 7.2m above pump floor,in order to guarantee no-interference with the on going working schedules&the daily activities inside &around the MPH and to guarantee the safety of the operation teams as well.

An innovative method for rehabilitation works (demolition and erection of new roof) was proposed by erection of an overhead platform (to isolate and confine the rehabilitation works well above the pumps level, thus avoiding any interference in the working schedules of the pump station)and then the design erection of light weight roof. The overhead platform will be supported on the RC crane beams that run parallel to the main axes of the MPS at a height of 7.2m above the pump floor [Fig 3].

Due to practical reasons it was decided to carryout the required works in two stages, by carrying out the demolition & erection of one half of the MPS roof at a time and then shifting to the other second half upon completing the first half.

Conceptual designs & drawings, for the overhead platform and the light weight roof (corrugated metal sheet roof), together with the technical specifications for materials and workmanship and bill of quantities were prepared by UKCC study team [Fig. (3)].

The study team identified the essential items in rehabilitation works to include:

- Design and erection of a light weight overhead platform resting on the reinforced concrete (RC) crane beams 8.6m apart at a height of 7.2 m above

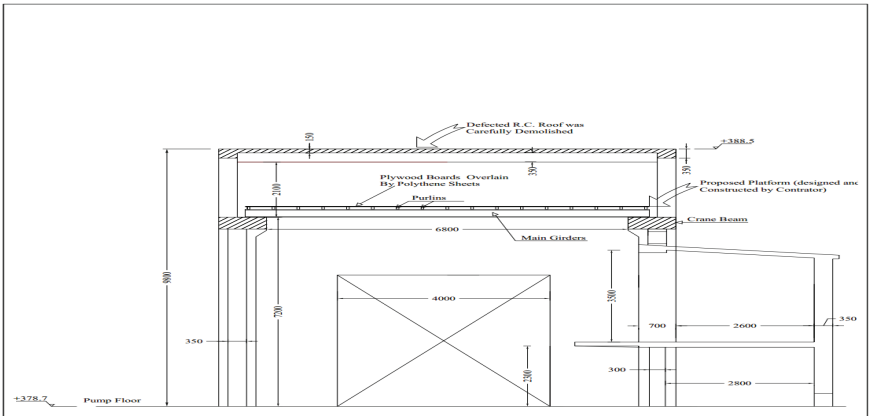

Fig (3): Proposed Platform

Fig (3): Proposed Platform.

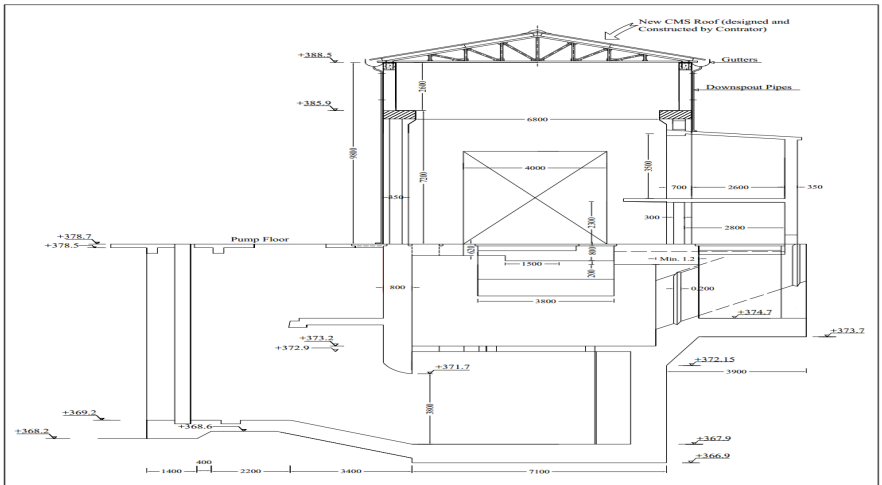

Fig (5): Typical Section Of The New Corrugated Metal Sheet (CMS) Roof

Fig (4): Typical Section of the Proposed Corrugated Metal Sheet (CMS) Roof.

ing the already critical situation and pave the way for the leakage of water through the roof slab into the MPS.

-Steel reinforcement of the RC roof slab panels& main beams showed signs of rusting (de coloring of concrete surfaces in the vicinity of the cracks).

- Large through cracking of one column at its head - due to excessive deflection and rotation of the roof main beam supporting it – was noticed.

- Neither the water proofing coats for water tightness of concrete surfaces, nor the light weight concrete (khafgi) layer, for surface draining of storm water from roof & heat insulation of the roof, were executed during the construction stages, rendering the roof vulnerable to accumulationof storm water (pond) &leaking into the MPS through the RC roof slab .

- The depth of concrete section of the main beam, which is spanning 8.6m, was under sized- the actual depth (L/17) is less than the depth (L/10) necessary to meet deflection requirements.

-Inherited, residual permanent deflections of the roof panels noticed at different locations noticed were likely to be due to the yielding/settlement of the props (supports) of the formwork for the roof system which might have occurred during construction stage in addition to the effect of concrete creep during the past four decades.

- The quality of the workmanship was generally acceptable.

4.2 The Recommended Rehabilitation and remedy:

The team of the structural assessment study recommended the following:

- Immediate demolition of the existing defected concrete roof system [Fig. (3)];

- Erection of a light weight roof in place [Fig 4];

- The required rehabilitation works (demolition of the RC roof and erection of light weight roof in place)to be executed by an experienced Construction Contractor;

- The rehabilitation works should not interrupt or affect the operation schedules of the MPS;

- Safety of personnel and equipment inside the station must be guaranteed.

The Authorities of the Sudanese Sugar Co. Ltd. (SSCL) and ASF administration,became aware of the catastrophic economical effects that might be incurred, if a sudden failure of the roof of MPH occurred- such as reduction in the production of sugar cane or an untimely shutdown of the Sugar Factory - and were so concerned of how to deal with this critical situation. This urged the authorities to seek the advice of the University of Khartoum Consultancy Corporation (UKCC) for the rectification of this critical situation.

This technical paper embodies the outcome of the the structural assessment, design of an innovative method for the rehabilitation of the RC roof and the procedures followed by the siteworks to accomplish the task successfully and timely, and without stopping operations of the MPS operations.

4. The structural assessment of the roof of the MPS and The recommended rehabilitation:

4.1 Assessment:

UKCC consultant's team, formed in July, 2014, conducted a structural assessment for the structural components of the defected roof of the MPS through the following activities:

- Site visits of MPS for visual inspections;

- Reviewof available structural drawings;

- Classification of the type of cracks;

- Estimation/measurement of deflections;

- Assessment of the environment of working conditions and the schedules of operation of pumps at MPS.

The results of the structural assessment [1] of the RC roof were as follow:
- The deflections of both RC roof slab panels & main beams far exceed the acceptable limiting values.
- Crack's widths in the RC main beams & slab panels exceeds the acceptable limiting values.

- Formation of two large water ponds on the RC deflected roof, which last for the whole rainy season, added additional loads to the roof, thus worsen-

The Main Pump House(MPH) is a reinforced concrete framed building, it's structural components comprised of a slab & beam roof, having plan area of 8.5*36.0 sq.m.,at a height of 9.8 m. above ground or pump floor; two sub-basements (suction or receiving basins) cast monolithically with the pump house; overhead crane that runs along two RC crane beams at a height of 7.2m. above the ground or pump floor; control room attached to the pump house. The discharge basin is located north of MPS at a distance of about 20.0 m from it, [see figs.(1)& (2)and plates (1), (2) ,(3) & (4)].

The MPH accommodates five centrifugal axial pumps, each having a capacity of 4.0 cu.m per second.

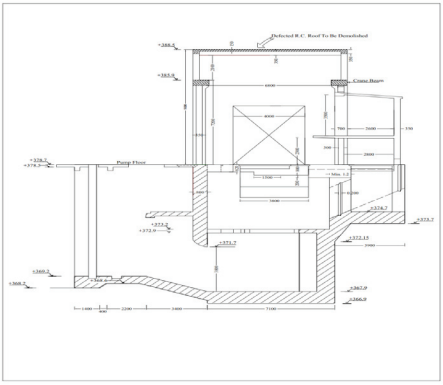

Fig (1): Sectional Elevation of Main Pump House

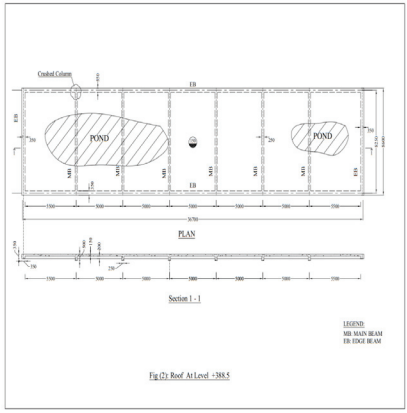

Fig (2): Roof At Level +388.5

Fig (2): Roof Plan at Level +388.5

3. Statement of the problem.

The reinforced concrete roofing system (slab panels framed by beams) of the MPS experienced noticed excessive deflections, over the past span of time since its construction, (especially the three western panels) associated with wide flexural cracks in the main beams and slab panels resulting in the breakage of one column at its head. These excessive deflections caused accumulation of rain/storm water on top of the roof and then leaking into the pump house.[Fig 2].

This situation makes the roof of MPS in a state of incipient failure, thus endangering the safety of the pumps inside the MPS and the pumps operation team.

Map (1): location of Assalaya Sugar Factory Scheme.

2. Description of the Main Pump Station (MPS).

The MPS of the scheme lies on the eastern (right) bank of the White Nile (WN) river, near Rabak city (capital of the WNS), situated at distance of 600.0 m from the bank of WNand connected to it by a tail canal.

Map (2): Main Pump Station of Assalaya Sugar Factory.

قصور في تصميم العارضات في السقف، ومشاكل في التشييد السقف تمثلت في ترخيم موروث ناتج عن هبوط دعامات القوالب اثناء صَب الخرسانات، وعدم تنفيذ المعالجات (الخرسانة الخفيفة/ الخافجي) في السقف لتسهيل تصريف مياه الامطار، عدم تنفيذ العازل المائي للسقف؛ وأوصت الدراسة الى ضرورة إزالة سقف المبنى الخرساني على وجه السرعة، وتركيب سقف خفيف من الألواح المعدنية المضلعة مكانه.

عملية التاهيل المقترحة واجهتها عقبة استحالة إيقاف تشغيل المضخات اثناء عمليات التاهيل، وبالتالي استحالة العمل من داخل المبنى خشية تأثر برنامج تشغيل المحطة لري المشروع الزراعي.

فريق الدراسة ابتكر طريقة سهلة وأمنة للتأهيل، وذلك بتصميم وتركيب منصة علوية مستندة على الكمرات الخرسانية الساندة لقضان الرافعة العلوية. هذه المنصة شكلت الأرضية لتلقي الأنقاض الناتجة من عمليات الإزالة، ولوضع المعدات ومواد السقف الجديد لتسهيل حركة عمال التاهيل المشرفين.

الشركة السودانية للسكر عملت مناقصة للتأهيل ووقع الاختيار على شركة حسن المشرف للتجارة والتشييد المحدودة لتنفيذ الصيانة والتأهيل تحت إشراف الهيئة.

قامت الشركة بتنفيذ كافة عمليات التاهيل وفق ما قدم من تصور بواسطة فريق الدراسة – من تصميم وتصنيع وتركيب المنصة العلوية، وكسر وإزالة السقف الخرساني، وتصميم وتركيب سقف الألواح المعدنية – بمهنية وكفاءة عالية.

خلصت الورقة الى ان البعض من المنشآت الصناعية القديمة التى شيدت في القرن الماضي، والتي تعاني من بعض مشكلات التصميم او التشيد تحتاج الى مراجعة وفحص لتحديد نوعية المشاكلات التى تعاني منها بواسطة جهات فنية مقتدرة؛ تفعيل برامج الصيانات الدورية الوقائية لضمان استمرار أداءها بكفاءة؛ ان عمليات الصيانة والتأهيل لمثل هذه المنشأت تحتاج الى دراية وخبرة وعناية من قبل المهندسين المستشارين وشركات المقاولات؛ وان مثل هذه الاعمال تحتاج الى تفعيل إجراءات الصحة و السلامة اثناء عمليات التاهيل.

1. Introduction.

Assalaya Sugar Factory (ASF) is a state owned sugar production factory, which was established in 1979 and started its operations in Jan.15,1980. ASF lies in White Nile State (WNS), at a distance of 280km south of Khartoum City (the NationalCapital of Sudan), [Map 1].Its maximum production capacity is 110,000 tons of sugar per year; the area of the agricultural scheme is about 35,000 fedans (14,700 hectares),irrigated from White Nile (WN). The irrigation system, in this scheme, comprised of a tail canal, main pump station (MPS), major canal, booster pump stations (BPS), minor canals, network of irrigation& drain canals.

The rehabilitation works were constrained by the impossibility of carrying out any works from the pump floor due to the strict operation schedules of the pump station in order not to affect the irrigation of the agricultural scheme.

The study team invented an innovative method for the required rehabilitation works, by designing & erecting an elevated platform resting on the crane beams. This platform protects the pumps underneath; intercepts the debris resulting from demolition operations and serves as working space for erection of the new roof.

Hassan Almusharf for Trade and Construction Company Ltd. was entrusted by the Sudanese Sugar Company Ltd. to carryout the rehabilitation works under the direct supervision of UKCC experts. The rehabilitation works were carried out satisfactorily and within the specified time frame.

This technical paper concludes that some industrial structures which were constructed on the last century requires inspections by qualified experts to identify structural deficiencies; the importance of adoption of routine maintenance programs for such structures; the rehabilitation of such structures require highly qualified experts and experienced contracting companies; adoption of tough Heath &Safety measures is a prerequisite of such works.

مستخلص

مصنع سكر عسلاية يقع شمال مدينة ربك بولاية النيل الأبيض. تأسس المصنع وبدا إنتاجه في العام 1981م، بطاقة 110 الف طن سكر في السنة. المشروع الزراعي يروى من النيل الأبيض عبر منظومة ري تتكون من قناة ذنابية، ومحطة ضخ رئيسية، وقناة رئيسية ناقلة، ومحطات ضخ داعمة، وشبكات قنوات فرعية للري ومصارف.

مبنى المضخات الرئيسية عبارة عن مبنى هيكلي خرساني يحوي خمسة مضخات رئيسية، ورافعة علوية وملحق بها غرفة الضبط والتشغيل، ويوجد على مبعدة منها – عند مدخل القناة الناقلة – حوض الرمي. العناصر الانشائية للمبنى مكونة من اساس الحصيرة، وحوض او بير السحب في القبو، وبلاطة المضخات، واعمدة، وعارضات الرافعة، ومنظومة السقف الخرساني (بلاطات مؤطرة بعارضات).

منظومة السقف بالمبني كان على وشك الانهيار، نتيجة الترخيم والهبوط الزائد عن الحدود المسموح به، مصحوبة بصدوع كبيرة في العارضات الخرسانية والبلاطات، وتجمع مياه الامطار فوق السقف في شكل بركتين كبيرتين كانتا تدومان طوال فترة الخريف مسببة في تسرب المياه عبر الصدوع والشقوق الى داخل المبنى.

إدارة شركة السكر السودانية، ولإدراكها بالآثار الكارثية علي مصنع في حالة انهيار السقف، كلفت هيئة جامعة الخرطوم الاستشارية لدراسة الحالة الانشائية للمبنى والتوصية بما يلزم لتدارك الامر قبل وقوع الكارثة (انهيار السقف). الهيئة بدورها كلفت فريقاً من مستشاريها للقيام بالدراسة اللازمة، ووضع المعالجات، والإشراف عليها.

هذه الورقة هي خلاصة ما قام به فريق المستشارين المكلف في كل مراحل الدراسة والتاهيل المختلفة حتى عاد المبنى آمناً. قام الفريق باجراء دراسة للمبنى في يوليو 2014م، وخلص الى وجود

(Technical Note)

An Innovative Method of Rehabilitation of the roof of the Main Pump House at Assalaya Sugar Factory.

Yousif Tibin Musa[1] and Osman Abdelrahaman Aballa[2]

Abstract

Assalaya Sugar Factory Ltd. which lies in White Nile state north of Rabak city, was established and started its production in 1981 with a maximum production capacity of 110, 000.0 tons of sugar per year. The agricultural scheme is irrigated from White Nile River through irrigation systems composed of tail canal, main pump station, carrier canal, booster pump stations, and networks of irrigation canal & drains.

The pump house of the Main Pump Station is a reinforced concrete framed building, cast monolithic with sub-basements (suction basins), it accommodates five pumps, overhead crane and control room. A reinforced concrete discharge basin is located at distance to it.

The roofing system of the pumps house experienced excessive deflections associated with large cracks resulting in the accumulation of storm water during the whole rainy season, therefore rendering the roof at the state of incipient failure, and endangering the safety of the personnel & equipments inside the pumps house.

The Sudanese Sugar Co. Ltd., being aware with the catastrophic economical consequences incase a sudden failure of the roof occurred, entrusted the the University of Khartoum Consultancy Corporation (UKCC) to conduct structural assessment study and to recommend the necessary remedial measure in order to rectify this critical situation. The UKCC formed a team from its experts to carryout the required task and supervise the rehabilitation works.

This technical paper embodies the results of the study and process of the rehabilitation works.

The study team conducted structural study in June 2014 and concluded that the reinforced concrete roof beams were undersized; there exist inherited deflections due to construction defects (yielding of the props of the formworks); the water proof coat & the light weight concrete (khafgi) that facilitate roof draining were not executed. The team recommended immediate removal of the RC defected roof and erection of a light weight corrugated metal roof in place.

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5. Conclusions

The following conclusions may be drawn from the present study on the evaluation of the stress history expressed in terms of pre-consolidation pressure and over-consolidation ratio parameters from CPT data for various Sudanese cohesive soils types:

a) The CPT test has proven its usefulness and reliability in solving quickly and successfully some of these foundation problems in the regions where a sufficient experience has been gained in the interpretation of the test results.

b) Attempts to estimate the stress history parameters σp and OCR for the cohesive soil types studied through application of some empirical methods developed elsewhere were not successful despite their reported reliability and validity in the region where they have been proposed.

c) As the stress history parameters and CPT data of soils are influenced by many factors, a simple and direct relationship cannot be easily established between these soil variables. For the purpose of analysis, the soil samples were classified according to their types and selected parameters which included plasticity index (PI), cone tip resistance (qc) and friction ratio (R_f).

d) A linear regression analysis was performed to study the relationships between the effective pre-consolidation pressure (σ'p) and over-consolidation ratio (OCR) on one hand and the CPT data on the other. Generally, the analysis results indicated reasonable to strong relationships between OCR and the CPT normalized cone resistance (q_{cn}) for the differently analyzed data sets. However, the correlation was better in the regression models based on the PI and R_f than those based on the soil type and qc.

e) The OCR-qcn regression model based on the Rf seems to be the most preferable compared to the other three models for estimating the OCR from the CPT normalized cone resistance, qcn. The accuracy regression relationships established between the soil OCR and the CPT data can be improved by considering more data from future research works and site investigations.

It may be concluded that the models based on the PI and the R_f parameters give the best OCR-CPT relationships. Accordingly, the regression equations expressed in terms of R_f and PI parameters can be used in the absence of the definitive consolidation test data for estimating the OCR with a reasonable accuracy for soils similar to those studied. The accuracy of the developed relationships can be improved using data from future research studies and site investigations or other relevant sources.

Furthermore, the following factors may be considered for comparison to find which of the two models based on PI or R_f would be preferred for OCR evaluation from technical and practical viewpoints:

a) The CPT provides continuous information regarding the variation of measured data with depth, thus the R_f will be known at any penetrated depth.

b) The Rf is used worldwide to classify soils by applying well known schemes or charts developed in various countries. In Sudan, a method based on the CPT data was developed since 1980 [2] for the classification of local soils.

c) For a given soil, the OCR can be readily and rapidly estimated using CPT results since there is no need to obtain samples for laboratory testing as will be required for the equations based on the PI.

d) The effects of in-situ soil shear strength and stress state conditions on the OCR are reflected in the R_f value because they are indirectly related to the cone resistance of penetrated soils , and

e) The R_f may be determined for all soil types whereas the PI is a characteristic of plastic clay soils only. Such an advantage facilitates extending the R_f based OCR-q_{cn} relationships for non-plastic silty and sandy soils.

Considering the above factors, the OCR-q_{cn} regression model based on R_f may be ranked as the most preferable of the four different approaches for the evaluation of the OCR from the CPT data. The methodology for using the R_f regression model for OCR evaluation involves the following steps:

a) Determination of R_f for the soil material at the depth of interest from CPT data profiles

b) Selection of the appropriate R_f range from Table 5 for soil data sub-grouping, and

c) Substitution of the R_f value obtained in step (a) in the OCR-q_{cn} equation assigned for the R_f range specified in step (b).

other hand, the model based on the plasticity index (PI) gave the lowest standard error and an R^2 value slightly lower than that based on the R_f.

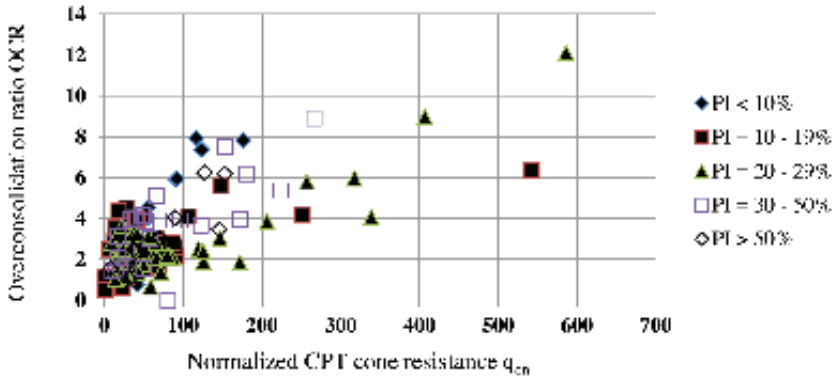

Fig. 5: OCR versus normalized CPT cone resistance q_{cn} for soils of different PI ranges

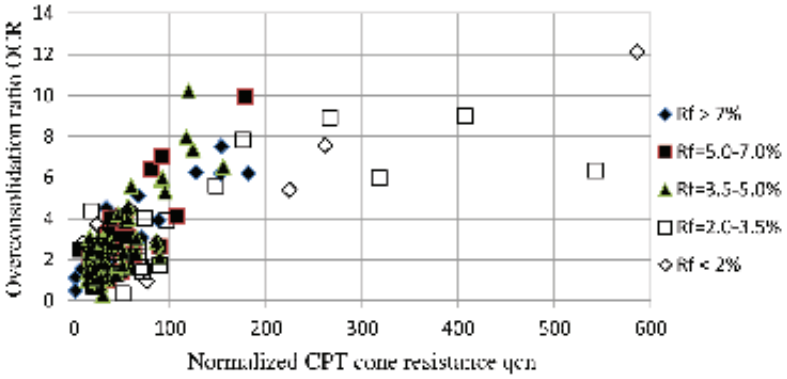

Fig. 6: OCR versus normalized cone resistance q_{cn} for soils of different CPT R_f ranges

4 . 5 Discussion of Regression Modeling Results

It is clear from the results of data analysis summarized in Tables 2 through 5 that in general reasonable to strong indirect relationships can be established between the OCR and q_{cn} for the cohesive soils by considering the effects soil type and condition indicated by certain indices or parameters.

High values of the regression analysis coefficients (R, R^2 and Adjusted R^2) were obtained for the SC soil type, non-plastic soils and soils with very high cone resistance (over 12MPa) or very low friction ratio (below 2%). Such high correlation coefficients indicate strong relationships between the OCR and q_{cn} for these particular soil types.

Similarly, reasonable correlation relationships have been indicated between OCR and q_{cn} with R^2 and adjusted R^2 values in the ranges of 0.61 to 0.793 and 0.577 to 0.782 respectively for the data sets pertaining to the other soil subgroups. There are, however, some variations in the results derived analysis in the four data sets considered to model the OCR and q_{cn} relationships. Generally, the degree of correlation was better for the data analyzed in terms of the soil plasticity index (PI) and the CPT friction ratio (R_f) than in terms of the soil type and cone resistance (q_c).

For the purpose of an overall rating of the four regression models the data given in Table 6 below were deduced from analysis results to examine which of them gives the best OCR-q_{cn} correlation.

Table 6: Ranges and average values of regression analysis results

Regression model based on	Coefficient of determination R^2		Standard error	
	Range	Average	Range	Average
Soil type	0.774 – 0.626	0.683	1.132-1.348	1.200
Plasticity index	0.776 – 0.645	0.730	1.042-1.145	1.064
CPT cone resistance	0.859 – 0.654	0.723	0.776-1.956	1.216
CPT friction ratio	0.845 – 0.645	0.747	0.982-1.539	1.261

A simple comparison was made on the basis of the values of the R^2 and standard error measures of regression analysis in Table 6. The average values of R^2 (0.683 to 0.747) and standard error (1.064 to 1.261) generally indicate reasonable and comparable correlation relationships for the different data sets. The highest and lowest average R^2 values were indicated in the OCR-q_{cn} models based on the friction ratio (R_f) and soil type respectively. On the

Table 3: Regression analysis results for data grouped in terms of plasticity index

Plasticity index (PI) %	Sample size	Best fit line equation	R	R^2	Adj. R^2	Standard error
Less than 10	29	$OCR = 0.046q_{cn} + 0.674$	0.887	0.786	0.778	1.044
10 - 19	44	$OCR = 0.011q_{cn} + 2.116$	0.847	0717	0.710	1.046
20 - 29	38	$OCR = 0.015q_{cn} + 1.322$	0.879	0.772	0.766	1.042
30 - 50	22	$OCR = 0.021q_{cn} + 2.123$	0.814	0.662	0.645	1.145
Over 50	9	$OCR = 0.028q_{cn} + 1.189$	0.844	0.712	0.671	1.042

c) Data Based on CPT Results

The soil data were divided in two main groups each consisting of five sub-groups of specified cone resistance q_c and friction ratio, R_f ranges. Regression analysis was performed and the results obtained are presented in Tables 4 and 5 for the q_c and R_f data sets respectively.

Table 4: Regression results for data grouped in terms of CPT cone resistance

Cone resistance, q_c (MPa)	Sample size	Best fit line equation	R	R^2	Adj. R^2	Standard error
0.50 – 2.00	21	$OCR = 0.072q_{cn} + 1.306$	0.825	0.681	0.664	0.776
2.00 – 5.00	40	$OCR = 0.040q_{cn} + 0.953$	0.809	0.654	0.645	1.122
5.00 – 8.00	34	$OCR = 0.025q_{cn} + 1.220$	0.837	0.701	0.692	0.999
8.00 – 12.00	14	$OCR = 0.051q_{cn} + 1.322$	0.781	0.610	0.577	1.956
12.00 – 20.00	15	$OCR = 0.019q_{cn}$	0.927	0.859	0.848	1.226

Table 5: regression results for data grouped in terms of cpt friction ratio

Friction ratio R_f (%)	Sample size	Best fit line equation	R	R^2	Adj. R^2	Standard error
Over 7.0	20	$OCR = 0.034q_{cn} + 1.230$	0.891	0.793	0.782	0.982
5.0 – 7.0	21	$OCR = 0.047q_{cn} + 0.728$	0.845	0.714	0.699	1.227
3.5 – 5.0	40	$OCR = 0.049q_{cn} + 0.56$	0.794	0.645	0.636	1.322
2.0 – 3.5	27	$OCR = 0.013q_{cn} + 2.102$	0.858	0.737	0.725	1.539
Less than 2.0	16	$OCR = 0.018q_{cn} + 1.405$	0.920	0.845	0.834	1.237

range of the above soil parameters or indices. For the data set pertaining to each subgroup, the OCR values were plotted against the normalized cone resistance q_{cn}. Outlier data points which appear too large or too small in comparison to the other values have not been included in the analysis. Such points may be resulting from incorrect experimental process, calculation and/ or sampling or the observed value is due to different mechanism other than that guides rest of the data set.

Linear regression analysis was then performed to establish the relationships between OCR and q_{cn} for all soil subgroups using the Microsft Excel built-in statistical package. The following output data were obtained from regression analysis for the various data sets:

e) Slope and y-intercept of the best fit straight regression line
f) Coefficient of correlation, R
g) Coefficient of determination, R2
h) Adjusted coefficient of determination, Adj. R2
i) Standard error.

4.4.2 Data Analysis for Different Soil Groups

a) Data Based on Soil Type

In this data set, the soil samples were divided in four subgroups based on the USCS Scheme; low plastic clay soils (CL); highly plastic clay soils (CH); silty soils (ML-MH) and clayey sand soils (SC). The results of the linear regression analysis are summarized in Table 2.

Table 2: Regression analysis results for data grouped in tems of soil type

Soil Type	Sample size	Best fit line equation	R	R^2	Adj. R^2	Standard error
CH	33	OCR = 0.015qcn + 1.917	0.791	0.626	0.614	1.348
CL	36	OCR = 0.030qcn + 1.987	0.831	0.690	0.680	1.171
ML-MH	37	OCR = 0.037qcn + 1.681	0.690	0.643	0.633	1.132
SC	18	OCR = 0.020qcn + 0.201	0.880	0.774	0.760	1.147

b) Data Based on Plasticity Index

The samples in this data set were divided into five subgroups: (i) non-plastic and low plastic soils of PI < 10%, (ii) soils of PI = 10 to 19% (iii) soils with PI = 20 to 29% (iv) soils of PI = 30 to 50% (v) soils of PI > 50%. The results of linear regression analysis carried out are given in Table 3.

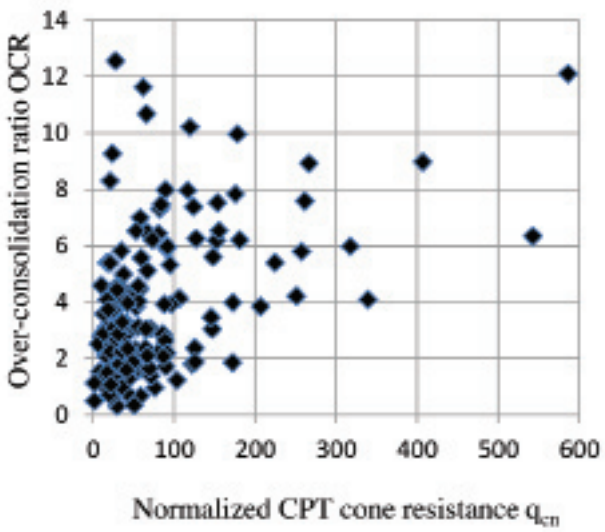

Fig.4 Relationship between over-consolidation ratio and CPT normalized cone resistance

4.4 Modeling the OCR and CPT Relationships for Selected Soil Subgroups

4.4.1 Selection of Soil Sub-Group for Analysis

The relationship between the OCR and q_{cn} in Figs. 3 seems to be slightly more defined than in σ'_p versus q_{cn} plot In Fig. 4 as indicated from the lower degree of data scatter and the higher computed R^2 value and inferred by the patterns of data variations in the two figures. This implies that a more promising correlation could be established between the CPT q_{cn} and the OCR rather than the σ'_p. Thus, the main emphasis in this study was devoted to study the possibility of developing a relationship between the OCR and q_{cn} soil variables.

The following parameters which qualitatively or quantitatively reflect the type and condition of soils have been considered in an attempt to establish reliable relationships between OCR and the CPT:

a) Soil type designation using the USCS scheme
b) Plasticity index (PI)
c) CPT cone tip resistance (q_c), and
d) CPT friction ratio (R_f)

For simplicity of comparison, the data pertaining to all soil samples can be arranged in four main sets or groups under the above headings. These groups were further divided into subgroups each representing a type or a specified

in R^2 is more than one would expect to see by chance. The regression line efficiency can also be evaluated through the estimation of standard error such that the smaller the variance between observed and estimated variable values the better is the model. A linear regression analysis was used to examine the relationship between the stress history and the CPT data of the soil types covered by this study.

4.3 General Relationships Between CPT and Stress History Parameters

To study the relationship between the stress history parameters and the CPT data, the values of the pre-consolidation pressure σ'_p and over-consolidation ratio OCR determined for all soil samples were plotted against the normalized cone resistance $(q_c-\sigma_{vo})/\sigma'_{vo}$ as shown in Figs. 3 and 4 respectively.

Figs. 3 and 4 show general variation trends that the σ'_p and OCR tend to increase with the normalized cone resistance however the degree of data scatter is very significant in both plots. This clearly indicates that no simple and direct relationships exist between any of the two stress history parameters and the CPT data. The high degree of data scatter may be attributed to the fact that the σ'_p OCR and CPT results are influenced by several factors probably the most important are the type and condition of the soils. The effects of such factors were indirectly considered as discussed in the subsequent sections in order to develop useful correlation between the σ'_p or OCR and the CPT data.

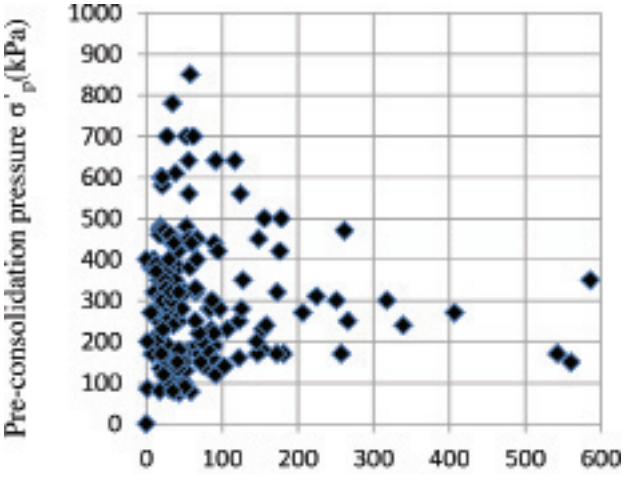

Fig.3 Relationship between pre-consolidation pressure and CPT cone resistance

soil types considered in this study. Comparisons were made between the σ'_p and OCR values determined from consolidation test results and the values estimated according to corresponding empirical methods. Unfortunately, the application of the three empirical methods has not revealed any good agreement between measured and estimated data. None of the three methods proved to be successful in yielding sound or meaningful predictions of the σ'_p and OCR for the Sudanese soil types considered. This is not unusual considering the complex stress history behavior, the empirical nature of the relationships and doubt with respect to their applicability to soils different from those for which they have been developed.

In view of the unsuccessful outcome of applying the empirical methods to evaluate σ'_p or OCR parameters from CPT data, consideration has been directed towards attempts to development of new relationships for the Sudanese soils.

4 . 2 Modeling of Variables Relationships by Linear Regression Analysis

Linear regression analysis is often used to develop a mathematical relationship between an independent and dependent soil variables or parameters representing a set of data. This is done by adjusting the observations to define the slope and intercept of the straight line that best predicts the dependent variable from the independent variable. Various measures may be used to assess the "goodness" of regression model in explaining the relation between the two variables. These include the data scatter plots, residual values around the regression line, coefficient of correlation R, coefficient of determination R^2, adjusted R^2 and standard error.

The scatter plot shows the direction, strength, and shape of the relationship between the variables and can also be used to spot outliers and nonlinear association. The residual value is the deviation of a particular point from the regression line. For a perfect fit the line passes through all points and thus the residual value in any point is zero. However, such an ideal case rarely exists and normally the line fits through data points such that sum of squares of residual expressed as the ratio of variance is minimized. The ratio of variance would be 0 if two variables are perfectly related however this ratio would fall between 0 and 1 in most cases. Mathematical subtraction of the ratio of variance from 1.0 gives the value of the coefficient of determination R^2, a measure of how well the model fits the data. An R^2 value close to 1.0 indicates that almost all of the variability specified in the model has been accounted for. The value of R^2 is, in turn, closely related to coefficient of correlation R and the adjusted R^2. The use of an adjusted R^2 is to take account of the increase in R^2 value when extra explanatory variables are added to the model. Unlike R^2, the adjusted R^2 increases only when the increase

3. Database of Consolidation Test Results and CPT Data

The soil database used in this study was obtained through compilation of consolidation test and CPT data from previous research studies undertaken at BRRI on Sudanese soils and some relevant data from previous geotechnical reports prepared for several infrastructure projects. Such soil data pertain to sites located in Khartoum State and several other states of the country. In total, 125 data pairs of clayey soils (CL and CH), silty soils (ML and MH) and sandy soils (SC and SM) were considered for analysis.

A static CPT machine with a mechanical adhesion jacket cone was used throughout in these research studies and investigations for performing tests very close to the locations of boreholes drilled to obtain undisturbed samples for laboratory testing. The CPT profiles were used for determining the cone resistance (q_c) and friction ratio (R_f) at the depths from which the soil samples were taken in the adjacent boreholes. The oedometer tests were performed on undisturbed soil samples to determine the σ_p' and OCR using the appropriate e–log p curves according to the Casagrande method. The soil index properties and stress history parameters ranges pertaining to the different soil types covered in this study are summarized in Table 1 below.

Statistical regression analysis was carried out based on the database obtained for the evaluation of the stress history parameters of the types of soil considered from CPT data as described below.

Table 1: Ranges of the index properties, CPT data and stress history parameters of studied soils

Soil type	Sample size	Fines content (%)	Atterberg limits		CPT Data		1D Odometer test Data	
			(%) LL	(%) PI	q_c (MPa)	(%) R_f	σ_p (kPa)	OCR
CH	33	97 - 60	118 41-	82 - 24	14.0 – 0.8	10.0 – 1.0	610 - 75	9.0 – 1.0
CL	36	97 - 50	50 - 26	34 - 7	20.0 – 0.8	9.0 – 0.1	480 - 78	12.0 – 0.3
ML-MH	37	99 - 32	63 - 23	21 – 0	21.5 – 0.1	10.0 – 0.8	780 - 80	13.0 - 0.5
SC	18	50 - 27	85 - 23	52 - 6	19.0 – 3.0	7.5 – 1.3	500 - 80	11.6 – 0.3

4. Analysis and Discussion of Study Results

4 . 1 Validity of Previous CPT and Stress History Parameters Correlations

To examine the usefulness of some of the previous methods to predict soil history parameters from the CPT data, the methods given in Equations 1, 2 and 3 tested for their validity in estimating the σ'p and OCR for the Sudanese

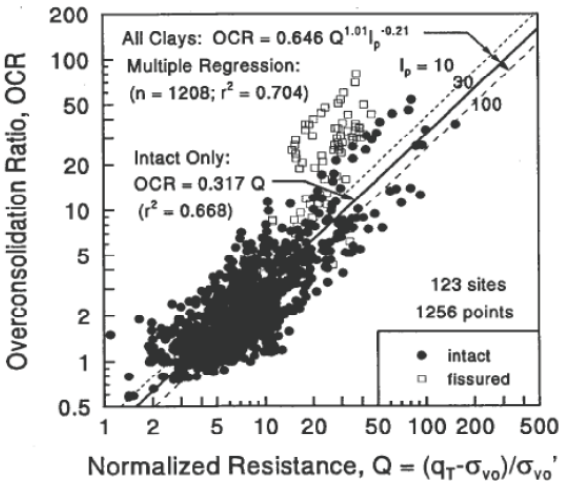

Fig. 2 Relationship between over-consolidation ratio and normalized CPT cone resistance [15]

Mayne et al [16] developed the following unified regression equation for evaluation of effective pre-consolidation pressure in soils in terms of the net CPT piezo-cone resistance:

$$\sigma_p' = 0.33\ (q_c - \sigma_{vo})^{m'}(\sigma_{atm}/100)^{1-m'} \qquad (4)$$

The exponent m' was related to the CPT material index I_c defined in Eq. 5 below as a function of normalized cone resistance Q_{tn} and sleeve friction F_r [8]:

$$I_c = [(3.47 - \log Q_{tn})^2 + (1.22 + \log F_r)^2]^{0.5} \qquad (5)$$

Based on the review of experience gained in previous studies it seems that the CPT method is a useful tool for the evaluation of the soil stress history parameters σ_p' and OCR. The present study is considered as a continuation of research on this important aspect of the CPT applications. More specifically, it has two objectives; firstly, to examine the usefulness of some published predictive methods based on CPT for evaluation of the OCR and σ_p of Sudanese soils and; secondly, to attempt developing new relationships using the available relevant soil database in case they are not applicable.

The importance of establishing relationships between the soil types and characteristics determined from the conventional testing methods and the static CPT is that some theoretical and empirical solutions of foundation engineering problems are based on the CPT. The development of CPT brought the attention on the possibility of using the test data for the evaluation of σ'_p and OCR stress history parameters [8,9]. The first direct and simple relationship of $\sigma'_p \approx q_c/3$ was proposed in 1979 [10] between σ'_p and the cone resistance (q_c) for the soil deposits in eastern Europe. This was further rectified by including the soil overburden pressure, σ_{vo} [11]. Several other theoretical models in which the σ'_p or OCR were related to the CPT data were proposed by several authors [11, 12, 13]. The following empirical relationship between σ'_p and the net cone resistance ($q_c - \sigma_{vo}$) was developed for Canadian clays [10].

$$\sigma_p' = (q_c - \sigma_{vo}) / N_{\sigma t} \qquad [2]$$

$N_{\sigma t}$ in Eq. 2 denotes a factor that was found to be highly dependent on the soil properties in different sites with reported values of 2.5 and 3.28 in two studies based on world soil data [14, 15]. A typical relationship showing the variation of the pre-consolidation pressure (σ_p') with the net cone resistance ($q_c - \sigma_{vo}$) is shown in Fig.1. The relationship in Eq. 3 and graphically depicted in Fig. 2 was proposed using a large number of data points between the soil OCR, the normalized cone resistance, Q and the soil plasticity index I_p [15]:

$$OCR = 0.646Q^{1.01}\, Ip^{-0.21} \qquad (3)$$

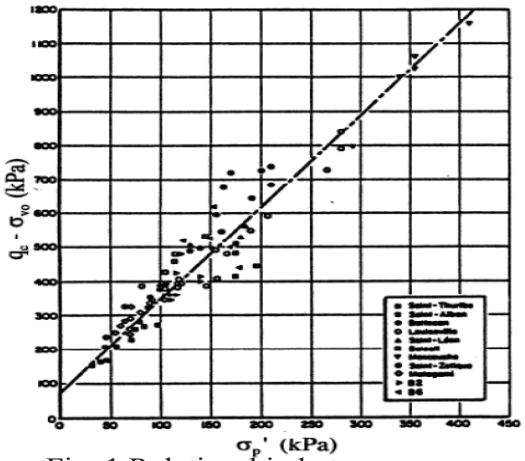

Fig. 1 Relationship between pre-consolidation pressure and net cone resistance [10]

tion, determination of physical and mechanical soil properties, estimation of soil bearing capacity, prediction of soil settlements and the design of shallow and deep foundations. Worldwide, numerous empirical and semi-empirical methods have been developed to evaluate geotechnical parameters for wide ranges of soil types and conditions from the CPT data. These evaluation methods vary greatly in their reliability and applicability.

Research on the CPT for Sudanese soils was initiated by the Building and Road Research Institute (BRRI), University of Khartoum in 1980 [2] and since then several studies have been undertaken to cover various aspects on the use of CPT for classification and evaluation of the geotechnical behavior of soils [3, 4, 5]. A review of the experience and research works carried out at BRRI on the use of CPT in Sudanese soils was presented by the author [6].

The main objective of this study is to examine the usefulness of the CPT technique in the evaluation of soil stress history of some Sudanese cohesive soils which are dominant in the upper subsurface strata in most central states of the country, particularly in Khartoum State.

2. Evaluation of Stress History of Cohesive Soils Using CPT Data; A Review

The soil stress history is an important geotechnical aspect and is normally expressed in terms of two main parameters; the pre-consolidation pressure (σ_p) and the over-consolidation ratio (OCR). The OCR is defined as the ratio of σ_p i.e. the maximum effective vertical stress a soil has experienced in the past to the present effective stress (σ_{vo}). The determination the OCR is of great importance as the strength, stress-strain behavior and the compressibility of soils are significantly affected by their stress history. The pre-consolidation pressure is determined by performing oedometer tests on undisturbed or remoulded soil samples but their results are influenced by sample disturbance, test procedure and the method of interpretation.

The pre-consolidation pressure and over-consolidation ratio have previously been related to some soil parameters or indices such as plasticity index (PI), liquidity index (LI), apparent soil cohesion (c_u) and undrained shear strength (s_u). For instance, the following relation was proposed for estimating the effective σ'_p in terms of the liquidity index (LI) and atmospheric pressure (p_a) [7]:

$$\sigma'_p / p_a = 10^{(1.11-1.62*LI)} \qquad (1)$$

المخروط المطبعة (q_{cn}) واعتبرت مجموعة مكونه من 125 من ازواج البيانات التى تمثل مختلف انواع التربة المتماسكة للتحليل فى هذه الدراسة . تم تحديد بيانات CPT باستخدام مخروط ميكانيكى ذو سترة التصاق فى أعماق مماثلة لتلك التى اخذت منها عينات التربة غير المخلخلة التى اجريت عليها اختبار التصلب. تم تصنيف اربع مجموعات للبيانات وفقاً لنوع التربة ، مؤشر اللدونة (PI) ، مقاومة المخروط (q_{cn}) ونسبة الاحتكاك (R_f) بغرض التحليل . كشفت نتائج التحليل عن وجود علاقات معقولة الى قوية بين المعاملين OCR و q_{cn} فى كل مجموعات البيانات ومع ذلك كانت درجة العلاقة افضل فى حالة مجموعتى البيانات المبنية على مؤشر اللدونة (PI) ونسبة الاحتكاك (R_f) مقارنة مع تلك المبنية على نوع التربة ومقاومة المخروط (q_c) . اعتبر نموذج العلاقة بين OCR و q_{cn} المبنى على نسبة الاحتكاك (R_f) أفضل من النموذج المبنى على مؤشر اللدونة (PI) لأنه ابسط وأكثر ملاءمة للتطبيق العملى. دقة العلاقات بين OCR و q_{cn} الناتجة عن هذه الدراسة تحتاج الى تحسين وتنقية اكثر عن طريق استخدام البيانات المستنبطة من البحوث والدراسات وتقارير فحوصات الموقع المستقبلية.

1. Introduction

The cone penetration test "CPT" is an important site investigation tool and one of the most commonly used techniques for the classification and characterization of soils in the field of geotechnical engineering.This test is carried out by statically pushing a standard mechanical or electrical cone of 60^o apex angle and $10cm^2$ cross-section through the soil at a constant rate of 20mm/sec. The main parameters measured in the CPT are the cone tip resistance (q_c) and sleeve friction (f_s) which are normally recorded at small depth intervals that can be as small as 5mm in modern CPT equipment.

The CPT has some advantages over the drilling and sampling methods [1]; which include:

- It is relatively quick, simple and economical
- It provides information on soils in their undisturbed or natural conditions
- It provides a continuous record of data measurement for the investigated depth
- It provides repeatable and reliable data i.e not operator dependent, and
- There are strong theoretical basis for CPT data interpretation.

The main disadvantages of the CPT are that no soil samples could be retrieved for visual inspection or laboratory testing and the penetration can be restricted in gravelly and highly cemented soil strata.

The CPT technique has been applied in various ways such as soil classifica-

Use of Static Cone Penetration Test for Evaluation of Over-consolidation Ratio of Some Sudanese Cohesive Soils

Abdul Karim Mohammad Zein[1]

Abstract

The aim of this study was to examine the usefulness of the CPT method in the evaluation of soil stress history parameters of some Sudanese cohesive soils. Database which pertain to sites in Khartoum and several other states in the country was deduced from the CPT and consolidation test results of previous research studies and geotechnical reports prepared at BRRI. Statistical linear regression analysis was performed to establish the relationships between over-consolidation ratio (OCR) and the normalized CPT cone resistance (q_{cn}). A total of 125 data pairs representing various cohesive soils were considered for analysis in this study. The CPT data were determined using a mechanical adhesion jacket cone at the depths corresponding to those from which the samples were taken for odometer testing. Four data sets grouped according to the soil type, the plasticity index (PI), CPT cone resistance (q_c) and CPT friction ratio (R_f) were considered for analysis. Generally, the analysis revealed reasonable to strong relationships between the OCR and q_{cn} in all data sets. However, the degree of correlation was better for the data sets based on PI and R_f soil parameters than those based on soil type and cone resistance (q_c). The OCR-q_{cn} regression model based on the R_f was considered to be more preferred for the evaluation of the OCR than that based on PI, because it is simple and more convenient to apply in practice. The accuracy of the developed OCR-q_{cn} relationships needs to be improved and refined using additional data from future research studies and site investigation.

Keywords: Cohesive soils, Stress history, Over-consolidation ratio, normalized CPT cone resistance, CPT friction ratio, Linear regression analysis.

مستخلص

تهدف هذه الدراسة لمعرفة فائدة طريقة اختبار المخروط المتعادل الاستاتيكى(CPT) لتقدير معامل تاريخ الاجهاد (Stress history) لبعض انواع التربة الطينية فى السودان . تم جمع قاعدة بيانات مستخلصة من نتائج اختبارات المخروط المتعادل الاستاتيكي (CPT) وتجارب التصلب (Consolidation) المعملية التى اجريت فى بعض الدراسات والتقارير الجيوتقنية السابقة بمعهد بحوث البناء والطرق . تم اجراء التحليل الاحصائى الخطى لاقامة العلاقات بين نسبة التصلب الآعلى OCR و مقاومة

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Building and Road Research Institute (BRRI), University of Khartoum

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CONTENTS

2.4 Tables:

- Tables should be numbered consecutively in the order in which they are referred to in the text (e.g. Table I).
- Table should be simple with brief column headings including unit and as few rows and columns as possible.
- Each table should have a caption or title (e.g. Table (3): Bricks properties) and the title to be at the top of the table.

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- Figures should be numbered consecutively in the order in which they are referred to in the text (e.g. Fig. 1).
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a- The paper should be written in correct manner either in Arabic or English Language.

b- The text should not exceed 5000 words or 15 pages size A4, double spaced.

c- The paper should be submitted to the secretary of the Journal in both hard and soft copy.

d. The paper should contain abstract of 200 words in length in English and Arabic.

e. The section and sub-section of the paper should be numbered.

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a. The first page should contain the following:
paper title; author(s) name(s) and their titles and addresses; abstracts in both Arabic and English language.

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c. Objectives.

d. Literature Review.

e. Materials and methods.

f. Results supported by tables, figures, photos, etc.

g. Discussion of results.

h. Conclusions and recommendations.

i. References.

j. Symbols and notion used if any.

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1.1 Scope:

In1985 Building and Road Research Institute (BBRI), University of Khartoum (U. of K.), took decision to issue a scientific biannual journal. The objectives of which are:

- Dissemination of information in the fields of building and road industry.
- Exchange of knowledge and experience in the afore-said fields.
- Publication of referred paper directed towards advancement of building and road industry and other BRRI publications such as:
  BRRI Digest, Technical Notes and BRRI News.

In 1997 the first volume appeared and now the 19th volume is under way. In November 2006 an International Standard Serial No. ISSN 1858-5019 was allocated for the Journal and its copy right procedures were accomplished. Papers published in the previous volumes were cited in the U. of K. web site: http:/brri.uofk.edu, e-mail: brri@uofk.edu

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We look forward to receive contributions for the coming volumes.

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Journal of Building and Road Research

Volume (19)

December. 2015

ISSN 1858-5019