

CASE STUDY

Construction delay impact on asphalt pavement structural performance: the case of N6 highway in Ghana

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Abstract

Cost, environmental, and social impacts of road construction delay have been widely investigated, but not its impacts on pavement structural performance. This study conducted pavement structural analysis and distress survey on a section of the N6 Highway in Ghana that had experienced more than a decade of construction delay to examine the impact of the delay on pavement structural performance. The pavement structure and its variants (representing different construction stages) were mechanistically modeled in WESLEA, a layered elastic pavement analysis program, to determine critical pavement strains for fatigue and rutting performance prediction. Also, various pavement structural design scenarios, simulating different construction stages and traffic loading, were analyzed using the American Association of State Highway and Transportation Officials (AASHTO) flexible pavement design procedure to examine the effects of construction delay on pavement structural capacity. The mechanistic analysis showed that trafficking a partially completed pavement considerably increases critical strain levels and exposes the pavement to a higher risk of fatigue and rutting damage. Large structural capacity deficits were obtained for the incomplete pavements: the thinner the in-situ pavement structure and the longer the construction delay, the greater the structural capacity deficit and the greater the damage risk. Opening incomplete pavement structures to traffic for a long time must be avoided because the associated high critical strains and inadequate in-situ structural capacity can induce premature failure, as corroborated by the distress survey findings. Construction staging specifications must be strictly enforced, while construction delay must be avoided and, if impossible, its effects minimized through effective project construction management.

Keywords: Construction Delay, Asphalt Pavement, Premature Failure, Mechanistic Analysis, Empirical Design, Fatigue Cracking

Introduction

Road construction delay has been widely studied, but attention has focused on its economic, environmental, and social impacts, such as project cost overrun, pollution, road user costs, and safety risks (e.g., Lo *et al.*, 2006; Beaty *et al.*, 2011; Mahamid *et al.*, 2012; Kamanga and Steyn, 2013; Al-Hazim and Salem, 2015; Van Dam *et al.*, 2015; Aziz and Abdel-Hakam, 2016; Tafazzoli and Shrestha, 2017; Karunakaran *et al.*, 2019; Lindhard *et al.*, 2020; Rivera *et al.*, 2020; Shrivastava and Singla, 2020), while the effects on pavement structural performance are rarely considered. While short delays may not be problematic, prolonged delays can prematurely initiate damage mechanisms to minimize pavement structural performance. The severity of damage and impact on pavement performance will depend, *inter alia*, on the construction stage at which the delay occurs, duration of the delay, and traffic loading. For instance, a situation where traffic is diverted onto one-half of a pavement cross-section for several years because of delayed construction of the opposing lanes could cause premature failures from the resulting concentrated traffic loading.

Road construction delays prevail in Ghana. For instance, 33 out of 48 projects executed between 2002 and 2013 experienced delays of up to 78 months (Amoatey and Ankrah, 2017). Delays can be longer than 78 months, such as on the reconstruction project of the Nsawam to Apedwa section of the N6 Highway, which commenced in 2008 and had not been completed as of 2021. Construction delays hinder sustainable road infrastructure development. They are often caused by

funding challenges, unfavorable site conditions, prolonged decision-making processes, change orders, poor construction management, and construction claims (Amoatey and Ankrah, 2017; Gomelesio, 2013; Ahmed, 2015; Akomah and Jackson, 2016; Ametepey *et al.*, 2017; Acheampong, 2019).

This current study investigated the impacts of construction delay on asphalt pavement structural performance, using the Nsawam–Apedwa section of the N6 Highway in Ghana as a case study. The objective was to demonstrate the implications of construction delays on asphalt pavement structural performance and longevity. The scope of the study involved a review of construction specifications on trafficking of roads under construction and mechanistic analysis of the pavement structural design of the case study road to examine the susceptibility of partially completed pavements to traffic-induced damage. Mechanistic pavement analysis uses mathematical models to calculate pavement stresses, strains and deflections in response to traffic loads. Also, pavement design analysis was conducted to investigate the impact of the construction delay on the structural capacity of incomplete pavement structures. A distress survey was conducted to relate the theoretical pavement analysis results to field performance. To begin with, an overview of the case study road is presented.

Case Study Road

The 41-km long Nsawam–Apedwa roadway is a section of Ghana's 250-km long N6 Highway (Figure 1). N6 connects the national capital (Accra) to the second largest city (Kumasi) and forms part of the Trans-African highway. Thus, apart from carrying local traffic, the case study road serves traffic from countries such as Burkina Faso, Mali, and Niger. The Nsawam–Apedwa section was previously a highly deteriorated two-lane roadway, which posed high road user costs and severe safety risks. The reconstruction involves the expansion of the roadway into a four-lane divided facility, where the new alignment generally follows the existing roadway, except for the first 10-

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km stretch, which bypasses the Nsawam township (near Accra). Also, an interchange is provided at Suhum, a town near Koforidua, to isolate local traffic operations from mainline traffic. Because there are no major intersections to significantly distribute truck traffic on the Nsawam–Apedwa section, nearly all heavy trucks traverse the entire section of the case study road. Upon completion, the project was expected to boost the local economy and promote regional trade by enhancing the accessibility of land-locked countries (e.g., Burkina Faso, Mali, and Niger) to Ghana's seaports.

According to traffic studies conducted by the project design team in 2005, annual average daily traffic (AADT) ranged from 6,800 to 10,000, with trucks comprising 20 % to 24 %. Estimates of annual traffic growth rate based on analysis of economic, population, and historical traffic data were between 5 % and 8 %. Accordingly, AADT at the end of the design period was predicted to range between 20,800 and 30,800, with truck volume comprising 21 % to 25 %. The design team utilized the American Association of State Highway and Transportation Officials (AASHTO) empirical flexible pavement design procedure (AASHTO, 1993) to determine an asphalt concrete (AC) pavement structure to accommodate a 20-year equivalent single axle load (ESAL) repetitions of 60 million over a subgrade with an effective resilient modulus of 80 MPa.

Table 1 shows the two sections considered by the design team, along with their recommended pavement design structure. Because of the similarity of the pavement designs, only that of the Nsawam Bypass to Apedwa sub-section was

selected for the mechanistic analysis conducted in this study. However, both sections were included in the pavement structural design analysis.

Construction started in December 2008 and was scheduled for completion in March 2012 (40 months). However, funding difficulties caused intermittent work stoppages to prevent timely project completion. As of August 2021, construction had halted, which suggested the project would most likely suffer a completion delay of over 10 years. The work suspensions had produced partially or fully completed pavement structures at various locations. Yet, a large portion of the roadway had been opened to traffic due to the strategic importance of the N6 Highway. Considering the discontinuous manner in which construction progressed, the pavement age varied. Depending on the time a particular section was constructed, it is possible that a partially or fully completed pavement section had been trafficked for up to about 10 years, which is one-half of the original design period.

As of 2021, the general construction status is illustrated in Figure 2; intersections are omitted for simplicity. As seen in Photo L in the figure, all four lanes at the Nsawam end (Labels A and B) are fully paved and marked, although their construction had progressed discontinuously. At about 10 km from the project start point in Nsawam, northbound traffic (Label B) was diverted onto one of the two southbound lanes (Label D) because of the incomplete construction of the remaining length of the northbound lanes (Label E). The diversion, as seen in Photo M, meant the remaining southbound lane (Label C) and the temporary northbound lane



Figure 1 Google map showing N6 Highway and the Nsawam–Apedwa section

Table 1 Pavement structural design of case study road

Layer	Pavement layer thickness (mm)	
	Nsawam Bypass (10 km)	Nsawam Bypass to Apedwa (31 km)
Wearing course	40	40
Binder course	60	60
^a DBM base	100	100
Crushed rock base	275	275
Granular subbase	325	300

^aDBM – dense bituminous macadam

(Label D) were under concentrated traffic loading. These two lanes (Labels C and D) carried the full design traffic load originally meant for the four lanes, although the entire section did not have the whole pavement structure in place. Interestingly, the northbound direction generally experienced heavier loading than the southbound direction due to freight transport from the southern seaports to northern destinations within and outside of Ghana.

Trafficking of roads under construction

Ghana’s Standard Specification for Road and Bridge Works (MOT, 2007) provides clauses for regulating the trafficking of roads under construction, and its key provisions are summarized as follows. Per Clause 9.13 of the Specification, if site conditions prevented the construction of diversion roads, pavement construction can proceed in half-width to allow traffic operation on the other half-width. There is a caveat to minimize the length of half-width building; however, with no length limitation mentioned, practices differ, and, when extensive delay occurs, concentrated loading can occur on a

considerable length of a partially or fully completed pavement.

Clause 5.5 requires uniform distribution of construction traffic over the entire width of embankments under construction. Because foundation soils may consolidate under the weight of a newly constructed embankment to cause large settlements or failures, Clause 1.28 requires that embankment earthworks are completed at least six months before base course construction begins, especially if foundation soils are prone to settlement. According to Clause 10.6, if surface runoff or trafficking causes distresses to develop on the surface of embankments, proper surface conditions must be restored before constructing the subsequent pavement layer.

Clause 12.6 requires that untreated subbases are open to traffic for at most two weeks; this provision does not apply to untreated bases. Trafficking is allowed on crushed rock subbase and base courses (Clauses 12.6) but prohibited on stabilized courses (Clause 14.11). Haulage of construction materials on completed pavements is permitted, provided axle loads do not exceed permissible limits (Clause 9.12). These specifications are meant to prevent premature pavement

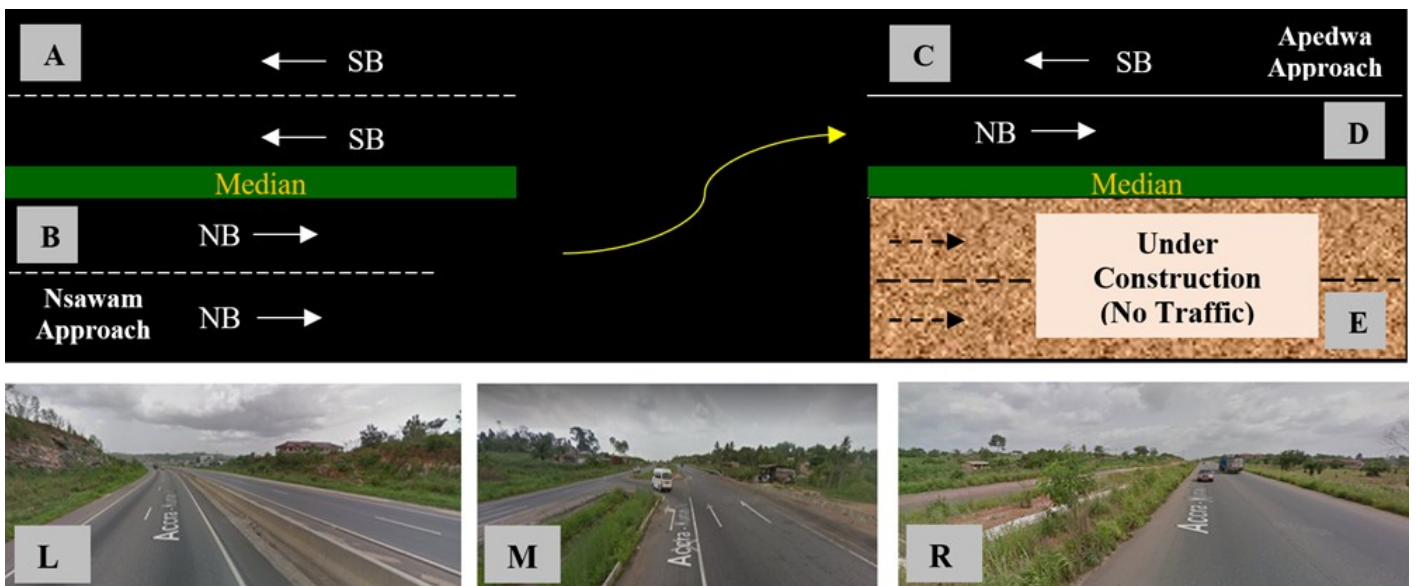


Figure 2 General status of construction on case study road (Photos from Google maps)

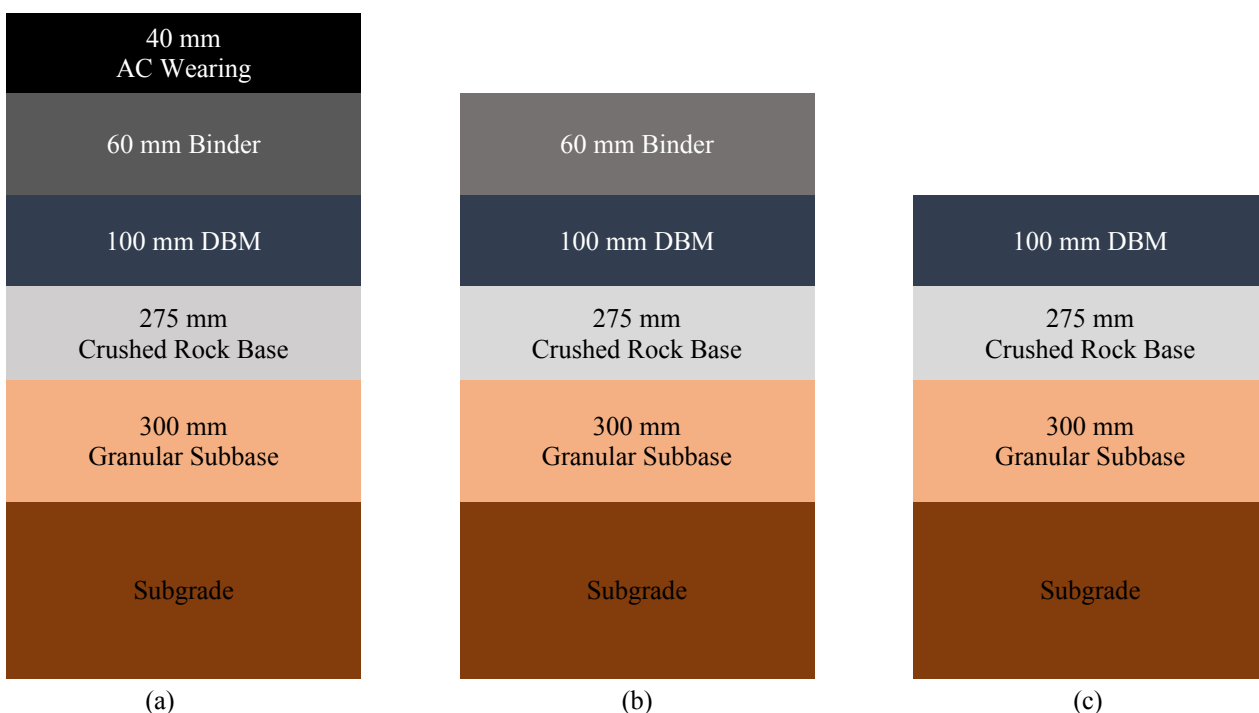


Figure 3 Pavement structure: (a) full structure, (b) no wearing course, and (c) no binder course

damage and to ensure an effective construction process. However, if construction delay becomes protracted, partially or fully completed pavement structures can suffer unanticipated high traffic loading, and the specification provisions become ineffective in ensuring adequate protection.

Mechanistic Pavement Analysis

Figure 3 shows the pavement cross-section design for the case study road and partial cross-sections representing various stages of construction. WESLEA, a linear elastic pavement analysis program, was utilized for mechanistic analysis of the three pavement structures, using the layer thicknesses in Figure 3 and the material properties in Table 2. The effective subgrade resilient modulus of 80MPa pertains to the case study road (as determined by the design team), and the other material property values are typical for asphalt pavement design in Ghana. Ghana’s load limit for a single axle with dual tires of 113kN was modeled in WESLEA (assuming a tire inflation pressure of 689kPa), and the maximum horizontal tensile strain at the bottom of the asphalt concrete (AC) layer and maximum compressive strain at the top of the subgrade was considered. These critical pavement strains are commonly used as failure criteria for bottom-up fatigue cracking and subgrade rutting, respectively.

Table 2 Material property values used in mechanistic analysis

Material	Modulus (MPa)	Poisson’s ratio
Asphalt concrete (AC)	3,000	0.35
Crushed rock base	300	0.40
Granular sub base	150	0.43
Subgrade soil	80	0.45

The critical pavement strains obtained from WESLEA and the AC modulus values in Table 2 were incorporated in Asphalt Institute’s (1982) fatigue cracking model (Equation 1) and subgrade rutting model (Equation 2) to predict fatigue and rutting performance, respectively. These models consider fatigue performance as the allowable number of load repetitions for fatigue cracking to cover 20 % of the pavement area, while rutting performance represents the permissible number of load repetitions to develop a rut depth of 12.5 mm. The fatigue cracking model in Equation 1 assumes a standard asphalt mixture with an asphalt binder volume of 11 % and air voids of 5 %.

$$N_f = 0.0796 \left(\frac{1}{\epsilon_t}\right)^{3.291} \left(\frac{1}{E}\right)^{0.854} \tag{1}$$

where N_f = allowable number of load repetitions to fatigue failure; ϵ_t = maximum horizontal tensile strain at AC layer bottom, $\mu\epsilon$; and E = AC mixture modulus, psi

$$N_r = 1.365 \times 10^{-9} \left(\frac{1}{\epsilon_c}\right)^{4.477} \tag{2}$$

where N_r = allowable number of load repetitions to rutting failure and ϵ_c = maximum compressive strain at subgrade surface, $\mu\epsilon$

The critical pavement strains and performance predictions obtained from the analysis are shown in Table 3. As expected, predicted performance decreases with decreasing pavement cross-section thickness. The entire pavement structure provides the highest predicted fatigue and rutting performance, although fatigue cracking controls the analysis. In the absence of a wearing course, the critical strain at the AC layer bottom increases by 24 % relative to the entire structure, resulting in a 50 % loss in expected fatigue performance. Accordingly, the critical strain on the top of the subgrade increases by 19 % to reduce expected rutting performance by 54 %. On the other hand, if the binder course is not paved and trafficking occurs on the DBM base course, critical strain at the AC layer bottom increases by 64 %, culminating in an 85 % reduction in predicted fatigue performance, while critical subgrade strain increases by 56 % to minimize expected rutting performance by 86 %.

The mechanistic analysis indicates that trafficking partially completed asphalt pavements increases critical pavement strain levels considerably and, hence, a higher likelihood for fatigue and rutting damage to occur. The thinner the in-situ AC layer, the greater the risk of damage. If a work stoppage is unavoidable, it is advisable to schedule it prior to the completion of the wearing course paving to minimize the risk of pavement damage.

Structural capacity analysis

In implementing the AASHTO design procedure (AASHTO, 1993), the design team utilized the inputs in the second column of Table 4, which were adopted for this study to examine the effects of construction delay on pavement structural capacity. Two construction stages were analyzed: no wearing course and no binder course. For each scenario, it was assumed the wearing or binder course paving had been delayed for 5 or 10 years, and the incomplete pavement had been trafficked for that time duration. Thus, if the paving was postponed for five years (i.e., 25 % of the 20-year design period), the partially completed pavement was considered to have received 15 million ESALs (i.e., 25 % of 60 million design ESALs). If paving was delayed for 10 years (i.e., 50 % of the 20-year design period), then 30 million ESALs (i.e., 50 % of 60 million design ESALs) would have been applied to the incomplete pavement. Thus, the part of the structural capacity analysis (Analysis A) involving 60 million ESALs pertained to the roadway section from the project start point at Nsawam to the location where northbound traffic diverted onto one of the southbound lanes, about 10km long (Figure 2)

Table 3 Critical pavement strains and performance predictions

Pavement Structure	Tensile strain at AC bottom ($\mu\epsilon$)	Compressive strain on Subgrade ($\mu\epsilon$)	Fatigue performance (million cycles)	Rutting performance (million cycles)
Full structure	170	213	3.3	37.4
No wearing course	210	253	1.7	17.3
No binder course	305	333	0.5	5.1

Table 4 Inputs for original pavement design and current structural capacity analysis

Parameter	Input		
	Original design	Capacity Analysis A	Capacity Analysis B
Design/trafficking period	20 years	5 years, 10 years	5 years, 10 years
Traffic loading (ESALs)	60 million	15 million, 30 million	17 million, 34 million
Reliability	95%	95%	95%
Standard deviation	0.45	0.45	0.45
Change in serviceability	4.5 – 2.0	4.5 – 2.0	4.5 – 2.0
Structural layer coefficients	0.40 (wearing/binder)	0.40 (wearing/binder)	0.40 (wearing/binder)
	0.23 (DBM)	0.23 (DBM)	0.23 (DBM)
	0.17 (crushed rock)	0.17 (crushed rock)	0.17 (crushed rock)
	0.12 (subbase)	0.12 (subbase)	0.12 (subbase)
Drainage coefficients	0.80	0.80	0.80
	(crushed rock /subbase)	(crushed rock /subbase)	(crushed rock/subbase)
Effective subgrade resilient modulus	80 MPa	80 MPa	80 MPa

The second part of the structural capacity analysis (Analysis B) covered the remaining 31-km long section; that is, the end of Nsawam Bypass to Apedwa (Labels C and D in Figure 2). Because of the traffic diversion, the two-lane roadway carried traffic meant for the four-lane divided highway. This implied the lane distribution factor of 0.9 used to calculate the original design ESALs of 60 million for the four-lane section did not apply to the two-lane section (Labels C and D in Figure 2) but rather a value of 1.0. Notably, the Ghana Highway Authority Pavement Design Manual (GHA, 1998) recommends a lane distribution factor – representing the proportion of the AADT that travels in the heavily loaded lane – of 0.9 for four-lane roadways (two lanes per travel direction) and 1.0 for two-lane roadways (one lane per travel direction).

Thus, the temporary two-lane roadway carried approximately 11 % more ESALs than it was initially designed to carry; hence, 67 million ESALs were used in the structural analysis for this section. For each of the two construction stages, assuming wearing or binder course construction had delayed for five years, the partially completed pavement would have received nearly 17 million ESALs (i.e., 25 % of 67 million ESALs), and, if paving had delayed for 10 years, the incomplete pavement would have been subjected to about 34 million ESALs (i.e., 50 % of 67 million ESALs).

The relevant inputs in Table 4 were then utilized in the AASHTO pavement design Equation (3) to solve for the required (design) structural number (SN) for Analysis Scenarios A and B. SN represents pavement structural capacity needed to support the design ESALs and protect the subgrade.

It is related to pavement layer thicknesses according to Equation 3. Using the layer thicknesses in Figure 3 and the layer and drainage coefficients in Table 4, it was straightforward to calculate the in-situ SN for the various incomplete pavements. Thus, the structural capacity analysis used SN as a surrogate to determine how well the in-situ structural capacity matched the design structural capacity. A greater structural capacity deficit suggested a greater risk of structural damage.

$$SN = a_1D_1 + a_2D_2m_2 + \dots + a_nD_nm_n \quad (3)$$

where a_1, a_2, a_n = layer coefficients of first, second and n -th layer, respectively; D_1, D_2, D_n = thickness of first, second and n -th layer, respectively; and m_2, m_n = drainage coefficients for the second layer and n -th layer, respectively.

Tables 5 and 6 show the resulting SN and structural capacity gaps. The structural capacity gap was computed as the difference in the in-situ and required SN divided by the in-situ SN and expressed as a percentage. Both the structural capacity and mechanistic analyses show similar, expected trends. The thinner the in-situ AC layer and the longer the construction delay, the higher the critical strains or, the more significant the structural capacity gap, and, consequently, the greater the propensity for pavement damage. Preferably, the total AC thickness must be paved before opening the road to traffic. While short-term trafficking of an incomplete pavement may not pose significant pavement damage risk, long-term loading can cause premature damage, particularly if the in-place AC

Table 5 Structural capacity analysis results for four-lane section (Analysis A)

Pavement structure	Trafficking (years)	ESALs (million)	In-Situ SN (Equation 3)	Required SN (AASHTO equation)	Structural capacity gap (%)
No wearing course	5	15	4.6	4.3	7
	10	30	4.6	4.7	-2
No binder course	5	15	3.7	4.3	-16
	10	30	3.7	4.7	-27

Table 6 Structural capacity analysis results for two-lane section (Analysis B)

Pavement structure	Trafficking (years)	ESALs (million)	In-Situ SN (Equation 3)	Required SN (AASHTO Equation)	Structural capacity gap (%)
No wearing course	5	17	4.5	4.4	2
	10	34	4.5	4.8	-7
No binder course	5	17	3.6	4.4	-22
	10	34	3.6	4.8	-33

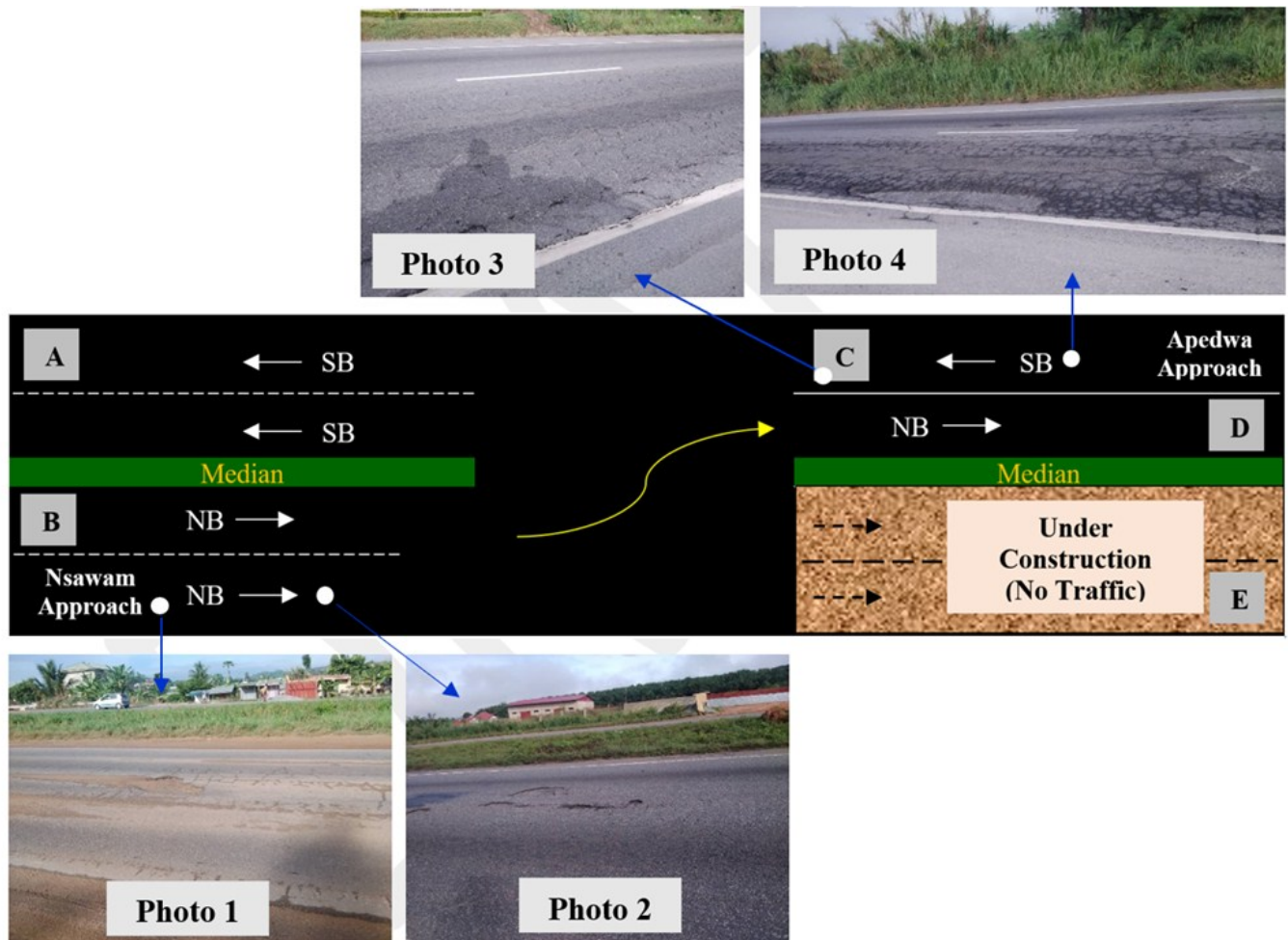


Figure 4 Pavement distresses on case study road

layer is so thin. As the results in both tables suggest, the structural capacity shortfall begins to be concerning when the wearing course has been absent for over five years. If the binder course was missing and trafficking occurred on the DBM base, the risk of damage becomes pronounced due to the increased structural capacity deficit. The effect of the concentrated traffic loading resulted in a more significant structural capacity gap (Analysis B) and, coupled with the increased critical strain levels noted in the mechanistic analysis, the two-lane section can be expected to experience more significant deterioration.

.Pavement performance

A windscreen pavement distress survey conducted on the case study road in June 2021 showed severe structural distresses, particularly fatigue cracking (Figure 4). There were two key observations from the survey. Although it might have been constructed earlier, the distresses on the four-lane section (Photos 1 and 2) generally appeared less severe than those on the two-lane section (Photos 3 and 4). Traffic load distribution over the four-lane section, compared with load concentration on the two-way section, considerably influenced the disparity in the pavement deterioration.

The second notable finding is in Photos 3 and 4, taken on the two-lane section, where the northbound lane (Label D) shows more severe deterioration than the southbound lane (Label C). The northbound lane truck traffic mainly carries freight from the southern seaports to destinations within and outside Ghana. The concentration of freight traffic over a single lane (Label D) considerably contributed to the observed severer deterioration. In a nutshell, the distress survey findings corroborated the mechanistic and structural capacity analysis results.

Conclusions

Mechanistic and structural capacity analyses, as well as a distress survey, were conducted on the Apedwa to Nswam section of the N6 Highway in Ghana that had experienced over 10 years of construction delay to examine the impact of the delay on pavement structural performance. Conclusions and recommendations drawn from the study are as follows:

- Trafficking of incomplete pavement structures increases critical strain levels and, hence, the likelihood of developing fatigue cracking and rutting damage. The thinner the in-situ pavement structure, the greater the risk of damage.
- The partially completed pavements showed a considerable structural capacity gap. The thinner the in-situ pavement structure and the longer the construction delay, the greater the structural capacity deficit and the greater the propensity for pavement damage.
- Opening partially constructed pavements to traffic for an extended period poses a significant risk because such a practice increases critical pavement strain levels, and combined with limited in-situ structural capacity, pavement damage can quickly occur.
- Structural capacity deficit started becoming concerning when the wearing course had been unpaved for over five years. Hence, if work suspension is unavoidable, it should occur when the paving of the wearing course is pending to minimize the extent of pavement damage.
- The distress survey findings corroborated the pavement analysis results that high pavement damage risk corresponds with concentrated traffic loading and limited in-situ

structural capacity. Hence, specifications on half-width road construction and construction staging must be effective and strictly enforced, while construction delays must be avoided, or its adverse impacts mitigated through proper road construction project management.

Conflict of Interest Declarations

The authors have no conflict of interest to declare.

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