ASHGHAL

Interim Advice Note No. 101

Amendments to QHDM

ADVICE

This Interim Advice Note (IAN) provides information and guidance on amendments and additions to the 2015 edition of Qatar Highway Design Manual (QHDM) Volume 2, Part 12 Pavement Design

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Qatar Deserves The Best

Circulation: **Ashghal Departments, Contractors, Supervision Consultants, Design Consultants, PMCs.**

Application: This Interim Advice Note (IAN) applies with immediate effect from the date of approval.

Rev	Date	Reason for Issue	Author	Checked	Approved
1	01.10.2015	For Implementation	**Dr. Walaa Eldin Ibrahim** QA/QC Expert	**Theocharis Tzavelas** Senior QA/QC Specialist	**Abdulla Ahin A A Mohd** Manager of Roads Design Department

	Signature	Date
Author:		29.10.2015
Checked:		29.10.2015
Approved:		29/10/2015

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1. Foreword

1.1 Interim Advice Notes (IANs) may be issued by Ashghal from time to time. They define specific requirements for works on Ashghal projects only, subject to any specific implementation instructions contained within each IAN.

1.2 Whilst IANs shall be read in conjunction with the Qatar Highway Design Manual (QHDM), the Qatar Traffic Manual (QTM) and the Qatar Construction Specifications (QCS), and may incorporate amendments or additions to these documents, they are not official updates to the QHDM, QTM, QCS or any other standards.

1.3 Ashghal directs which IANs shall be applied to its projects on a case by case basis. Where it is agreed that the guidance contained within a particular IAN is not to be incorporated on a particular project (e.g. physical constraints make implementation prohibitive in terms of land use, cost impact or time delay), a departure from standard shall be applied for by the relevant Consultant / Contractor.

1.4 IANs are generally based on international standards and industry best practice and may include modifications to such standards in order to suit Qatar conditions. Their purpose is to fill gaps in existing Qatar standards where relevant guidance is missing and/or provide higher standards in line with current, international best practice.

1.5 The IANs specify Ashghal's requirements in the interim until such time as the current Qatar standards (such as QHDM, QTM, etc.) are updated. These requirements may be incorporated into future updates of the QHDM, QTM or QCS, however this cannot be guaranteed. Therefore, third parties who are not engaged on Ashghal projects make use of Ashghal IANs at their own risk.

1.6 All IANs are owned, controlled and updated as necessary by Ashghal. All technical queries relating to IANs should be directed to Ashghal's Manager of the Roads Design Department, Infrastructure Affairs.

Signed on behalf of the Ashghal – Infrastructure Affairs - Roads Design Department:

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2. Ashghal Interim Advice Note (IAN) – Feedback Form

Ashghal IANs represent the product of consideration of international standards and best practice against what would work most appropriately for Qatar. However, it is possible that not all issues have been considered, or that there are errors or inconsistencies in an IAN.

If you identify any such issues, it would be appreciated if you could let us know so that amendments can be incorporated into the next revision. Similarly, we would be pleased to receive any general comments you may wish to make. Please use the form below for noting any items that you wish to raise.

Please complete all fields necessary to identify the relevant item			
IAN title:			
IAN number:		Appendix letter:	
Page number:		Table number:	
Paragraph number:		Figure number:	
Description comment: Please continue on a separate sheet if required:			
Your name and contact details (optional):			
Name:		Telephone:	
Organisation:		Email:	
Position:		Address:	

Please email the completed form to:

Abdulla Ahin AA Mohd

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We cannot acknowledge every response, but we thank you for contributions. Those contributions which bring new issues to our attention will ensure that the IANs will continue to assist in improving quality on Ashghal's infrastructure projects.

3. Introduction

3.1 This Interim Advice Note takes immediate effect and shall be read in conjunction with:

- **QCS 2010 - Qatar Construction Specifications 2010**
- **QCS 2014 - Qatar Construction Specifications 2014**
- **IAN 011 - Cycleway Design Guidance**
- **IAN 021 - Cycleways and Footways Pavement Design Guidelines**
- **IAN 100 - Amendments to Section 6 Parts 3, 4, 5 & 6 of QCS 2014**
- **IAN 029 - Pavement Standard Details**

This IAN shall apply to pavement construction on relevant Ashghal projects. In the event of conflicts between this IAN and the above documents, this IAN 101 shall take precedence with respect to Ashghal projects.

4. Withdrawn / Amended Standard

This Interim Advice Note (IAN) shall take immediate effect and supersedes the following:

- **The relevant subsections of 2015 edition of QHDM as listed in this IAN**
- **IAN016 Pavement Design Guidelines Revision No. 3 (EXW-GENL-0000-PE-KBR-IP-00016)**
- **Supplementary Guidelines for Pavement Design for LR&DP Projects (PMC-GD-DES-014)**

5. Justification of the major changes

The major issues identified in the design methodologies currently used, and how they are addressed in this IAN are summarized below:

5.1 Layer properties and general design methodology:

- The IAN 016, for the application of the AASHTO 1993 methodology, requires designers to 'reduce' the asphalt concrete layer coefficients (a_i) to account for hot climate of Qatar. This approach, while appear to be logical, does not account for the added value of material specification requirements for asphalt binder and mixture listed in (IAN 100), which is designed such that the material placed in the road provides certain minimum capacity for the climatic condition of Qatar. In addition, it does not account for the variation is temperatures of pavement layers with season and with depth from surface. For example the binder grade required in the surface layers is selected to account for the warm climate and the traffic expected. The reduction in layer coefficients is also not practiced in other countries with similar weather conditions, such as the warm regions of Arizona and Southern California in the USA. It is recognized in the AASHTO 1993 procedure that mechanical properties of asphalt mixtures should be used to estimate layer coefficients. In addition, there has been significant progress in estimation of mixture moduli form volumetric properties and binder rheological properties, which a more sound approach for designers to use to estimate the layer coefficients. The methodology presented herein (see section 9.4.2) provides step-by-step guidelines for computation of the layer coefficients from pavement temperature, equivalent loading frequency (using the vehicle speed), the volumetric properties (e.g., gradation, void content etc.) of AC and the properties of the asphalt binder used in Qatar. A guideline is provided to select inputs based on the PMB grades required in Qatar.

- Polymer modified binders (PMBs) are specified in IAN 016, QHDM and QCS 2014, however their benefits were not considered during the pavement design. The step-by-step guidelines in section 9.4.2 allow designers to use actual or typical properties of PMB grades in pavement design, as specified in the IAN 100. This IAN 101 is the first to integrate the QCS 2014 requirements, its amendment in the IAN 100 for materials, and the pavement design inputs.
- In IAN 016, regardless of traffic level, minimum 5 Layer structure is required for expressways: 3 layers of AC (AC wearing course, AC intermediate course and AC base course), Base and Subbase. Considering the minimum lift thicknesses that are related to the maximum aggregate size, the total minimum thickness of ~430mm. For expressways that are designed for mainly passenger cars and light goods vehicles, which is the case for many urban roads in and around Doha, this is not justified, in particular when PMBs are used. The design procedure presented in this document requires minimum of two layers of AC (Base and Wearing course) and Base layer. The term 'AC intermediate layer' has been removed from the terminology. This standard allows thicker AC surface layer, which is to be constructed in multiple lifts when needed (see 9.1.2.1).

5.2 Traffic assessment:

- Importance of performing traffic count for existing roads was not strongly emphasized. This issue has been resolved in 9.2.1.
- No clear guideline was provided on how to estimate traffic growth rate. This issue has been resolved in 9.2.1.
- No clear guideline was provided on how to estimate the % HV and the truck load factors in the absence of WIM data. In fact the requirement to use Figure 7-1 in the MMUP document is not supported by MMUP experts, who indicated that the figure is only intended for intersection design. This issue has been resolved in 9.2.1.

5.3 Geotechnical considerations:

- In this IAN document, frequency of geotechnical investigation, types of tests needed and their limits were clarified and strongly emphasized.

6. Implementation

6.1 This IAN shall be implemented with immediate effect on projects as follows:

- Relevant Ashghal projects in design stage
- Relevant Ashghal projects in tender stage
- Relevant Ashghal Design & Build projects

6.2 Relevant Ashghal projects in construction stage shall be reviewed by the Supervision Consultant and Contractor and the implications of adoption of this Interim Advice Note discussed with the respective Ashghal Project Manager and Programme Management Consultant (PMC) where applicable. This shall include an assessment on the current design to determine whether it complies with this Interim Advice Note and the practicalities of modifying the design and construction in order to achieve compliance.

6.3 The only exceptions are:

- Projects already in construction, where a significant portion of construction and procurement has already occurred and design modification would not be economic or practicable.

6.4 If in doubt, Consultants / Contractors should seek guidance from their respective Ashghal Project Manager or designated Programme Management Consultant (PMC) on a scheme specific basis.

6.5 Where projects are in construction or final detail design, the impacts of this and related IANs are to be assessed by the designer, construction supervising consultant and Ashghal's Project Management Consultant (PMC) where applicable. If for a significant practical reason, a part of this IAN is not achievable in construction, the particular item and location where the particular condition of IAN cannot be applied must be approved by the Engineer as a departure from the design standard or specifications.

7. Disclaimer

This Interim Advice Note and its recommendations or directions have been provided for application on Ashghal's infrastructure projects within Qatar only and they are not warranted as suitable for use on other roads, highways or infrastructure within Qatar or elsewhere. Should any third party, consultant or contractor choose to adopt this Interim Advice Note for purposes other than Ashghal's infrastructure projects, they shall do so at their own risk.

8. Amendments to Volume 2, Part 12 Pavement Design

The following changes are related to section "3 Pavement Structure Basics". Add the following subsection after the subsection "3.2.4 Subbase".

3.2.5 Typical Flexible Pavement Structures

Typical flexible pavement structures are shown in Figure 3.2. The designer may select any one of the typical structures shown in Figure 3.2. The designer may also propose to eliminate and/or add a structural layer, with adequate justification. Brief information about each layer are provided below:

- The asphalt concrete wearing course must provide a skid resistant, smooth and quiet surface and should be both crack and rut resistant. Asphalt mixture used in this layer shall be designed using Superpave or Marshall design methods listed in IAN100 and QCS 2014 Section 6 Part 3. The asphalt mixtures shall be designed with high quality binders (e.g., Polymer-Modified) with performance grades PG76S-10, PG76H-10, PG76V-10 or PG76E-10, depending on the traffic level. However, due to its exposure to the extremes of temperature and high wheel load shear stresses, the wearing course will probably deteriorate and require replacement before the rest of the pavement. Resurfacing is likely to be required at intervals of approximately 6-8 years during the life of the road.
- The asphalt concrete base layer shall be primarily a fatigue resistant mixture with rich-binder content with Pen 60/70 grade (or PG64-10). Asphalt mixture used in this layer shall be designed using Superpave method or Marshall method listed in IAN100 and QCS 2014 Section 6 Part 3.
- Unbound aggregate base course shall be designed in accordance with the requirements listed in IAN100 and QCS2014 Section 6 Part 4.
- Cement-bound material (CBM) base course shall be designed in accordance with the requirements listed in IAN100 and QCS2014 Section 6 Part 6.
- Subgrade is the top layer of the natural soil and depending on the road geometry, will be either cut or filled. Subgrade shall conform the requirements listed in QCS2014 Section 6 Part 3.

The range of thicknesses of each course and corresponding lift thicknesses are shown in Table 3.2.

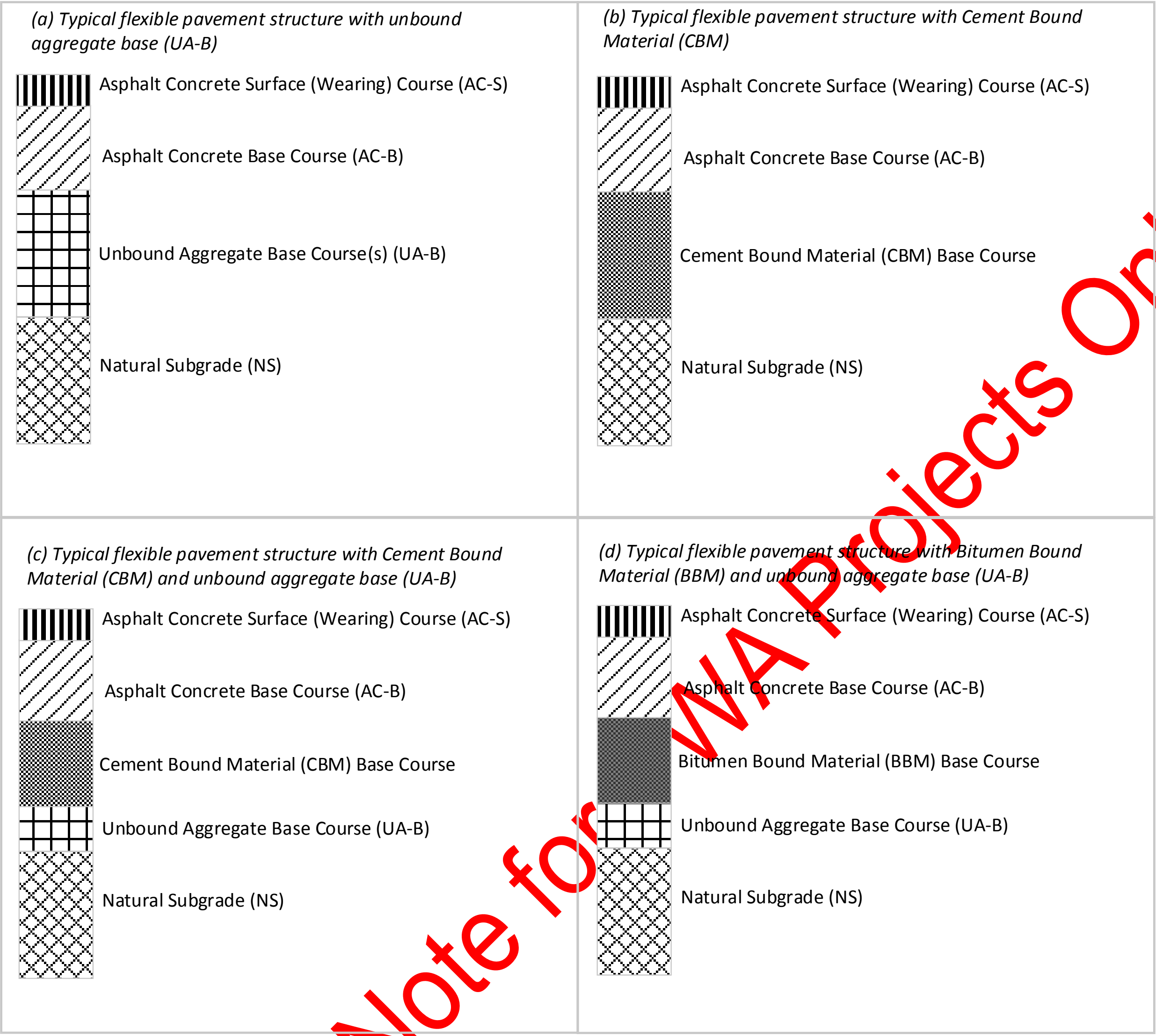


Figure 3.2: Typical flexible pavement structures

Table 3.1: The range of asphalt pavement course lift thicknesses for the State of Qatar

Pavement Course	Min. lift thickness (mm)	Max. lift thickness (mm)
Asphalt concrete surface course (AC-S)	2.5 * NMAS	4 * NMAS
Asphalt concrete base course (AC-B)	2.5 * NMAS	4 * NMAS
Unbound aggregate base/subbase course(s) (UA-B)	2.5 * NMAS	4 * NMAS
Cement-bound material (CBM)	2.5 * NMAS	4 * NMAS

8.1. AMENDMENTS TO SECTION 4 SUBGRADES

Replace the subsections "4.3 Subgrade Strength Determination" and "4.4 Parameters and Correlations" with the following:

4.3 Geotechnical Considerations

Pavement design procedure must include a consideration of the underlying subgrade soil conditions. The physical and chemical characteristics as well as mechanical properties of the subgrade soil will determine the thickness of pavement structure that can allow the transit of the design traffic volume and loading during the design life providing good service condition.

4.3.1 Geotechnical Investigation

The main objective of the Geotechnical Investigation is to supply information on the existing soil and ground water condition in order to derive recommendations on the suitability of the existing soil foundation.

The Geotechnical Investigation must be carried out in accordance with Table 4.3.1. When the specification limits listed in Table 4.3.1 are not fulfilled, either some of the subgrade material must be replaced with higher quality material or the amount of cover (fill height) shall be increased. Alternatively, the designer can propose different solution(s) for stabilization of existing subgrade.

Table 4.3.1: Selected Subgrade Specifications and Testing Frequency

Parameter	Standard	Specification Limits	Testing Frequency
Resilient Modulus (1)	ASTM D7369-11	14400 psi min	Every 500 m (or less) equally distributed along the route of the pavement being designed
California Bearing Ratio	ASTM D1883 (Soaked)	15% min at 95% Max. Dry Density	
In-place California Bearing Ratio	ASTM D4429	15% min	
Percent passing the 75mm sieve	ASTM D6913	100%	
Percent passing the 0.075mm sieve	ASTM D1140	30% max	
Liquid Limit	ASTM D4318 Method A	30% max	
Plasticity Index	ASTM D4318	10% max	
Organic matter		2% max	

Notes: (1) Resilient Modulus test is optional but strongly recommended. CBR test may be used in lieu of resilient modulus.

After all the topsoil (i.e., soil that includes organic matter/vegetation) is removed, the geotechnical investigation shall be carried out at the following depths:

- 0.0 – 0.5 m
- 0.5 – 1.0 m
- 1.0 – 1.5 m

If the Coefficient of Variation (CV) of the three tests is greater than 10% the minimum value should be selected for the trial pit while if CV is lower than 10% the designer should select the average value.

In the Pavement Design Report, at least at the detailed design stage, the designer shall include a Geotechnical Investigation Report and must define the design M_R value based on the analysis of data shown in the report.

In case of material replacement, cover or stabilization the designer shall provide physical characteristics as well as mechanical properties data for the selected option and specify the design M_R value by referring to this data.

4.3.2 Subgrade Design CBR and Resilient Modulus

AASHTO procedure requires subgrade resilient modulus (M_R) as one of the major inputs. The resilient modulus is a measure of the elastic property of the soil recognizing certain nonlinear characteristics. The resilient modulus can be used directly for the design of flexible pavements but must be converted to a modulus of subgrade reaction (k- value) for the design of rigid or composite pavements.

Because not all road agencies have the equipment to perform resilient modulus testing, there are several empirical correlations that have been developed to estimate M_R from other empirical parameters.

If running resilient modulus test is not possible, designer may use CBR test and compute the M_R empirically using Equation 1 in Table 4.3.2. Designer may also choose to use other equations listed in Table 4.3.2, with appropriate justification.

Table 4.3.2: Subgrade Modulus Correlations

Equation	Reference	Limitations
(1) $M_{R\ (psi)} = 2555 \cdot CBR^{0.64}$	**AASHTO 2002 Design Guide**	**A fair conversion over a wide range of values.**
(2) $M_{R\ (psi)} = 1500 \cdot CBR$	Heukelom & Klomp (1962)	Only for fine-grained non-expansive soils with a soaked CBR of 10 or less.
(3) $M_{R\ (psi)} = 3000 \cdot CBR^{0.65}$	AASHTO 1993 Design Guide	For non-fine-grained soils with a soaked CBR greater than 10.

Once Resilient Modulus values are obtained, the designer shall perform a statistical analysis in order to evaluate the Coefficient of Variation (CV) of the available dataset.

If the CV is greater than 10%, the average M_R value should not be used as the design M_R, and the Pavement Designer should look at segmenting the road project area into distinct sections with similar modulus values and designing those sections based on the average M_R of each section.

If no homogeneous sections clearly exist, designer shall use the 10^{th} percentile of the M_R values to obtain the design M_R. While calculating the 10^{th} percentile, normal distribution shall not be assumed. Instead, the cumulative distribution function shall be plotted against the CBR values and the 10^{th} percentile shall be obtained from the CDF versus CBR graph. This can be accomplished using the "PERCENTILE.EXC" function of MS Excel.

4.3.3 Subgrade Modulus backcalculated from Falling Weight Deflectometer (FWD) data

When Falling Weight Deflectometer (FWD) testing is conducted and the backcalculated resilient modulus is determined, then the design M_R shall be 1/3rd of the backcalculated M_R.

If CBR and backcalculated M_R results are available, use the smaller M_R for pavement design purposes.

For partially saturated soils, the stiffness is mainly dependent on the negative pore-water pressure or soil moisture suction. Therefore, the laboratory prepared specimen exhibits essentially the same stiffness as undisturbed specimens for comparable suction values.

During construction, the CBR shall be checked to verify that it is in conformance with the design assumptions for that section of pavement.

Final grading to subgrade level shall be carried out in conjunction with construction of subsequent layers so as to minimize the damage to the subgrade due to construction traffic and/or inclement weather.

If subgrade is too weak to handle the construction traffic then a capping layer should be considered to help protecting the subgrade from damage imposed by construction traffic.

The CBR values are measured using the AASHTO T193 or ASTM D1883, on soaked subgrade samples compacted to 95% of the maximum dry density (MDD).

The specified subgrade strengths must be sustained for a depth of at least 300 mm and the material below this must have a CBR, at the in-situ density, of at least 10%.

If the subgrade soil strength does not match the requirement of Table 3.1 of QCS 2014, then a capping layer should be provided. If designers adopt this solution, the Pavement Design Report shall include the design of the capping layer.

8.2. AMENDMENDS TO SECTION 5 AGGREGATE BASES AND SUBBASES

Replace the subsections "5.2 Aggregate Subbase" and "5.3 Aggregate Base Course" with the following:

5.2 Aggregate Subbase

Aggregate or unbound subbase shall be constructed from well-graded crushed rock, whose properties will be in accordance with the QCS 2014 and/or IAN 100. The minimum CBR for subbase shall be 70 percent.

5.3 Aggregate Base Course

Aggregate base will generally have similar features as the subbase, with tighter tolerances than subbase, and improved physical properties. The aggregate base course properties will be in accordance with the QCS 2014 and/or IAN 100. The minimum CBR for subbase shall be 80 percent. Recycled materials may be used in base course provided that they meet the specifications for base course.

8.3. AMENDMENDS TO SECTION 9 TRAFFIC ANALYSIS

Replace section 9 with the following:

9 TRAFFIC ANALYSIS

Traffic is one of the key inputs required for pavement design. It controls the pavement layer thickness and material type used in pavement construction. Overestimation of traffic in pavement design may lead to a thicker pavement structure than necessary with higher associated costs, while underestimation of traffic may lead to pavement structures that are thinner than needed and are susceptible to premature pavement failure, resulting in increased maintenance costs and a negative impact on the driving public.

The traffic analysis shall be performed in accordance with the general guidelines described in the following two cases:

- Case I – Existing Roads
- Case II – Non-Existing roads

Case I – Existing Roads

This case is followed when the project is an upgrade of an existing road or when the traffic expected on a new road can be clearly estimated from existing traffic on other existing roads that will be connected to the new road.

Estimation of Average Daily Traffic (ADT)

Classified traffic counts shall be performed and included in the pavement design report for existing roads even if significant changes in traffic levels are anticipated after the construction. The classified traffic count shall be used in the estimation of the current (normal) traffic level as well as the percentage of heavy goods vehicles (HGV%) and vehicle class distribution at the proposed project location.

Classified traffic counts shall be carried out using the vehicle classes presented in Table 9.1. The traffic counts shall be performed in both directions for a minimum of 5 consecutive days, excluding Fridays and Saturdays as well as times of abnormal traffic activity such as public and school holidays. During this period at least two traffic counts should be performed for a full 24 hours. The count totals for the other days should be factored up to obtain the 24 hour totals.

The average daily traffic (ADT) can be calculated for all vehicles or for each individual vehicle class by summing the traffic counts for all five days in both directions and dividing the total by five. The ADT should be converted to an annual average daily traffic (AADT) based on the appropriate factor and the number of count days and other applicable variables such as seasonal correction factors. In the absence of any relevant information, a factor of 1.0 can be used for the conversion.

In pavement design, only buses and trucks are considered in the analysis due to their disproportionate effect on the resulting pavement structure and future pavement performance. Motorcycles, passenger cars, and light pickup trucks are excluded from the analysis due to their relatively light weight and low impact on pavement performance. Therefore, the analysis of the traffic data shall focus on moderately heavy and heavy vehicles (i.e., light goods vehicles, midi buses, big buses, rigid trucks, articulated trucks, multi trailer trucks, and rigid trucks with trailers).

For major roadway projects, the five day counts shall be repeated several times throughout the year to ensure the accuracy of the ADT value.

Table 9.1: Truck Load Factors (TF)

Class	Type[a]	Axles[b]	GCC[c] Class	QHDM Class	GVW_{90}[d] (tons)	GVW_{FL}[e] (tons)	ESAL Factor for GVW_{90} (TF_{90})	ESAL Factor for GVW_{FL} (TF_{FL})	**Design ESAL Factor[f] (TF)**
C1	RT	11	2	5, 6	11.2	21.0	0.54	6.49	**3.51**
C2	RT	12	4,5	-	20.7	28.0	1.13	3.65	**2.39**
C3	AT	111	22	7, 8	7.9	34.0	0.04	12.15	**6.09**
C4	RT	22	10, 11	-	27.2	30.0	2.05	3.01	**2.53**
C5	RT	23	16, 17	-	26.7	39.0	0.74	3.25	**1.99**
C6	RT	32	50, 51	-	22.4	35.0	0.53	3.05	**1.79**
C7	RT	13	52, 53	-	20.5	37.0	0.38	3.89	**2.13**
C8	AT	112	23, 24	9	19.9	41.0	0.54	9.31	**4.92**
C9	AT	121	28, 29	11	23.5	41.0	1.03	9.31	**5.17**
C10	AT	113	25, 26	10	25.3	50.0	0.64	9.55	**5.10**
C11	AT	122	30, 31, 32, 33	12	24.9	48.0	0.50	6.47	**3.48**
C12	AT	114	27	-	30.1	49.0	1.06	7.35	**4.20**
C13	AT	123	34, 35	13	27.9	57.0	0.40	6.71	**3.56**
C14	AT	124	36, 37	-	30.7	56.0	0.43	4.51	**2.47**
C15	AT	222	40, 41, 42, 43	-	22.6	50.0	0.26	5.83	**3.05**
C16	AT	223	45, 46, 47	-	29.7	61.0	0.42	7.10	**3.76**
C17	AT	224	48, 49	-	25.2	58.0	0.15	3.87	**2.01**
C18	RT+T	1112	3	5+14	27.6	45.0	1.27	8.72	**5.00**
C19	RT+T	1211	6,7	-	26.2	46.0	0.69	6.29	**3.49**
C20	RT+T	1212	8,9	-	26.6	52.0	0.43	5.88	**3.16**
C21	RT+T	2211	12,13	-	28.7	46.0	0.86	5.54	**3.20**
C22	RT+T	2212	14,15	-	26.6	54.0	0.33	5.25	**2.79**
C23	LGV	11	2	5	-	7.6	-	0.09	**0.09**
C24	M. Bus	11	NA	3	-	10.0	-	0.26	**0.26**
C25	L. Bus	11	NA	4	-	18.0	-	2.64	**2.64**

Notes:

a. RT = Rigid Truck, AT = Articulated Truck, RT+T = Rigid Truck + Trailer, LGV = Light Goods Vehicle, M. Bus = Medium bus (e.g., School Bus, Mosque Bus), L. Bus = Large bus (e.g., Mowasalat buses).

b. 11 = single-single, 112 = single-single-tandem, 123 = single-tandem-tridem. See Appendix 101F for the images of each of these truck classes.

c. GCC truck types are available in Appendix 101F.

d. GVW_{90} = 90^{th} percentile Gross Vehicle Weight (GVW) obtained from the analysis of data from Weigh in Motion (WIM) stations located in Qatar.

e. GVW_{FL} = Fully Loaded Gross Vehicle Weight (GVW), i.e., the vehicle weight is equal to maximum legal limit.

f. ESAL Factor is calculated assuming that 50% of the vehicles are full loaded and 50% are loaded according to the 90 percentile data obtained from WIM stations in Qatar, i.e., $TF = 0.5TF_{90} + 0.5TF_{FL}$. Different numbers may be proposed by the designer if justification is provided (e.g., axle load survey, knowledge of production facilities, factories).

Adequate justification shall be provided if the ADT values used in the pavement design are different than those obtained from the classified traffic counts.

The designer shall estimate the diverted traffic that will be attracted to the road because of the improved pavement as well as the construction traffic and use them in the estimation of the initial year average daily traffic (ADT_i) as follows:

$$ADT_i = ADT_{classified\ count} + ADT_{diverted} + ADT_{construction} \quad [9.1]$$

where

ADT_i = Average Daily Traffic for the initial year

$ADT_{classified\ count}$ = Average Daily Traffic measured during the design stage

$ADT_{diverted}$ = Average Daily Traffic expected due to diverted traffic when the new pavement is open to traffic

$ADT_{construction}$ = Average Daily Traffic expected due to expected construction activity that affect the road to be designed.

<u>Traffic Growth</u>

The traffic growth trend shall be estimated from the QSTM full day model obtained at 2011, 2016, 2021, 2026, and 2031. The estimated *ADTs* for these years shall be plotted against time (i.e., years) and the traffic growth rate shall be estimated through a linear model (see Figure 9.1). The following linear model shall be used to describe traffic growth for pavement design purposes:

$$ADT_f = ADT_i(1 + R(f - i)) \quad [9.2]$$

where

ADT_f = Average Daily Traffic for the future year

ADT_i = Average Daily Traffic for the initial year

i = Initial year for ADT

f = Future year for ADT

R = Growth rate factor

In cases where an accurate linear fitting is not observed to the entire dataset, the designer may subdivide the ADTs into time intervals and estimate the growth rate for each interval.

The design report shall include a discussion of the future development plans and land use of the area surrounding the proposed project location to justify the selection of the growth rate value obtained using the QSTM predictions.

<u>Cumulative Design Standard Axles</u>

Once the traffic level (ADT_f) is calculated for each individual year, cumulative traffic shall be calculated using the following formula:

$$ADT_{total} = \sum_{f=1}^{20} ADT_f \qquad [9.3]$$

where

ADT_f = Average Daily Traffic for the each individual year

ADT_{total} = Cumulative Average Daily Traffic for the entire 20 year analysis period

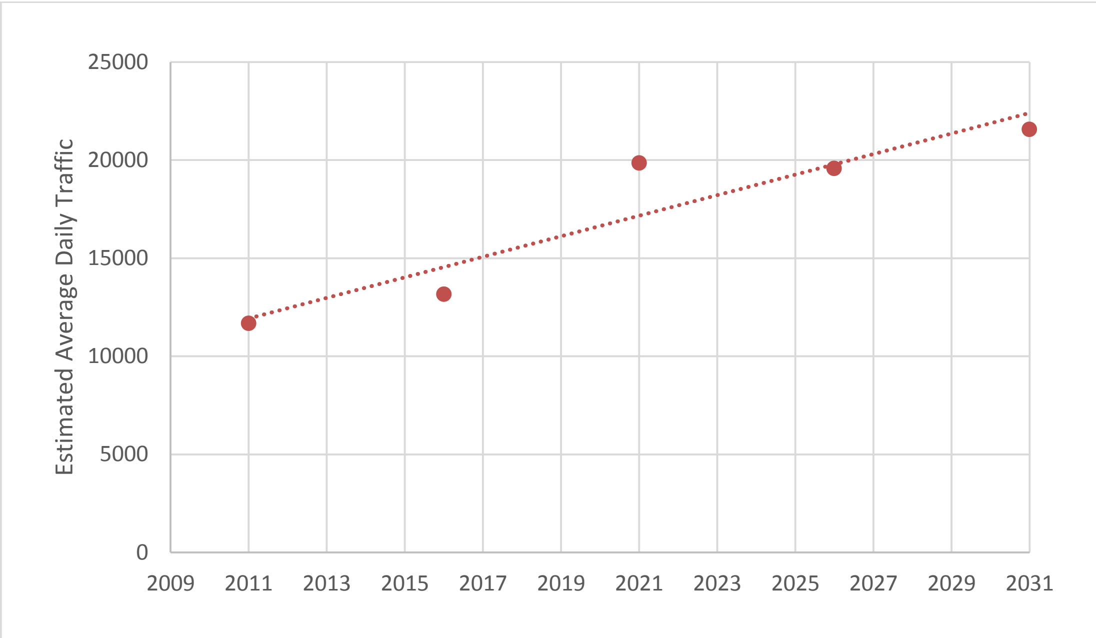


Figure 9.1 – Example linear growth model (dashed line) for traffic predictions of QSTM

The following equation shall be used to calculate the cumulative number of standard axles over the pavement design life <u>for each truck class</u>:

$$ESAL_{TC} = ADT_{total}(TC\%)(\mathrm{TF})(\mathrm{D}\%)(\mathrm{LN}\%)(365\,\mathrm{days/\,yr}) \qquad [9.4]$$

where

$ESAL_{TC}$ = Cumulative number of equivalent single axle loads for a particular truck class

ADT_{total} = Cumulative Average Daily Traffic for the entire 20 year analysis period

$TC\%$ = The percentage of truck traffic for a particular truck class

$\mathrm{D}\%$ = The directional distribution factor

$\mathrm{LN}\%$ = Lane factor

TF = Truck load factor

The equation 9.4 shall be used for each truck class, and the values obtained for all truck classes shall be summed in order to obtain the total number of ESALs for pavement design.

$$ESAL = \sum_{TC=1}^{N_{TC}} ESAL_{TC} \qquad [9.5]$$

Directional Distribution and Lane Factors

The average daily traffic (ADT) accounts for traffic in all lanes and both directions of travel. In order to estimate the required pavement design thickness, the ADT needs to be adjusted to represent loading in the design lane. This can be achieved by multiplying the ADT by the directional distribution factor (D%), which defines the percentage of trucks in the design direction, and the lane factor (LN%), which defines the percentage of trucks in the design lane.

For existing roads where it is possible to obtain classified traffic counts in both directions, the directional distribution factor shall be estimated by dividing the number of trucks in each direction by the total number of trucks in both directions, and taking the higher of the two values. If the directional distribution factor is greater than 55%, the design report shall include a discussion to support the use of the higher directional distribution value. The design report shall also include a discussion of any potential changes in the directional distribution of truck traffic upon the completion of the proposed project.

The lane factor shall be selected based on the number of lanes that are open to truck traffic. A lane factor of 100% shall be used for roadways with one lane per direction that is open to truck traffic; a lane factor of 90% shall be used for roadways with two lanes per direction that are open to truck traffic; and a lane factor of 80% shall be used for roadways with three or more lanes per direction that are open to truck traffic. The design report shall include a statement of the total number of lanes in each direction and the number of lanes that are open to truck traffic, along with the selected lane factor.

Truck Load Factors

The truck load factors presented in Table 9.1 shall be considered in the estimation of the equivalent single axle loads (ESALs) for pavement design under normal traffic conditions. These values were obtained by analyzing continuous Weigh In Motion (WIM) data collected along Salwa Road, North Road, and Dukhan Road (see Appendix 101E). These values shall be used with caution if unusual traffic conditions, such as the presence of a nearby quarry or major construction project, are observed. The designer may also calculate (and submit to the Engineer for approval) the Truck Load Factors (TF) from the 90th percentile of the Gross Vehicle Weight (GVW) obtained from a nearby Weigh In Motion (WIM) data. In such a case, a table similar to Table 101E – 1 (see Appendix 101E) shall be submitted and the Appendix D of the AASHTO 1993 guide (Tables D.1 through D.9) shall be followed to calculate the ESAL factors for each axle. An example of such calculation is given in Appendix 101E.

Case II – Non-Existing Roads

This case is used when the design is for a road in an area that is not developed yet or when the traffic expected on the new road cannot be estimated from near-by existing roads that will be connected to the new road.

Estimation of Average Daily Traffic (ADT)

For non-existing roads, the QSTM model can be used to estimate the initial year Average Daily Traffic (ADT). The initial ADT shall be estimated from interpolation of the “full day” (FD) QSTM intermediate year predictions.

The steps of obtaining future year ADTs and the cumulative traffic is the same as Case I.

The percentage of heavy goods vehicles (HGV%), including school and company buses, restricted and permitted heavy vehicles, and light goods vehicles, shall be estimated as a percentage of the total vehicles using the output from the FD model run of the QSTM.

It should be noted that the QSTM has not been calibrated using detailed truck traffic information. Therefore, care must be taken when using QSTM predictions of HGV% for pavement design. Designers are required to provide information from new or historical records for near-by roads of classified counts to justify the selection of the HGV% for the design.

It should be noted that the HGV% provided in the MMUP Guidelines (Figure 7-1 in the Guidelines and Procedures for Transport Studies - May 2011) are not meant for traffic loading estimation for pavement design, and thus are not allowed for pavement design purposes.

Traffic Growth

Same procedure described for Case I shall be used.

Cumulative Design Standard Axles

Same procedure described for Case I shall be used.

Directional Distribution and Lane Factors

The directional distribution factor can be estimated from directional traffic predictions obtained using the QSTM. If the directional distribution factor is greater than 55%, the design report shall include a discussion to support the use of the higher directional distribution value.

Truck Load Factors

Same procedure described for Case I shall be used.

8.4. AMENDMENDS TO 10.1 FLEXIBLE DESIGN PROCESS: 1993 AASHTO GUIDE

The following changes are related to section 10.1 Flexible Design Process: 1993 AASHTO Guide. Add the following text at the end of "Step 3: Select Layer Thicknesses" before "10.1.1 Example Flexible Pavement Design"

The AASHTO (1993) pavement design is an empirical method widely used in many countries around the world. The equation below is the AASHTO (1993) relationship that relates the structural capacity (Structural Number), subgrade resilient modulus, expected serviceability and reliability to the traffic level:

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\,[\log_{10}(SN+1)] - 0.20 + \left[\frac{\log_{10}\dfrac{\Delta PSI}{4.2-1.5}}{0.4+\dfrac{1094}{(SN+1)^{5.19}}}\right] + 2.32\log_{10}(M_R) - 8.07$$

[10.1.1]

where;

W_{18} = expected number of Equivalent Single Axle Loads (ESALs)

Z_R = standard normal deviate corresponding to the design reliability

S_o = standard deviation

ΔPSI = difference between initial design serviceability index, p_o, and the design terminal serviceability index, p_t ($\Delta PSI = p_o - p_t$)

M_R = subgrade resilient modulus (psi)

SN = structural number ($SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + ...$, where a_i= i^{th} layer coefficient, D_i= i^{th} layer thickness (inches), m_i= i^{th} layer drainage coefficient).

AASHTO (1993) general guidelines shall be followed to determine the thickness of each pavement layer. The parameters shown in Table 10.1.1 shall be used for serviceability and reliability. Drainage coefficients shall be estimated from percent of time pavement structure is exposed to moisture levels approaching saturation, using the AASHTO 1993 table shown in

Table 10.1.2. The procedures for obtaining other coefficients are explained in the following subsections.

Table 10.1.1: AASHTO (1993) inputs for serviceability and reliability for the State of Qatar

Road Class	Initial Serviceability, p_o	Terminal Serviceability, p_t	Standard normal deviate, Z_R (Reliability, R) (Rural)	Standard normal deviate, Z_R (Reliability, R) (Urban)	Standard Deviation, S_o (all roads)
Primary Routes *(Freeways & Expressways)*	4.2	3.0	-1.881 (97%)	-1.881 (97%)	0.45
Secondary Routes *(Arterials)*	4.2	2.5	-1.645 (95%)	-1.037 (85%)	0.45
Tertiary Routes *(Collectors)*	4.2	2.0	-1.282 (90%)	-0.841 (80%)	0.45
Local Routes *(Local)*	4.2	1.5	-0.841 (80%)	-0.674 (75%)	0.45

Table 10.1.2: AASHTO (1993) inputs for drainage coefficients

Table 2.4. Recommended m_i Values for Modifying Structural Layer Coefficients of Untreated Base and Subbase Materials in Flexible Pavements

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation: Less Than 1%	1–5%	5–25%	Greater Than 25%
Excellent	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

10.1.1 Layer Coefficients (a_i) for the Asphalt Concrete Courses

Asphalt mixtures are viscoelastic materials, whose responses to traffic loads are both time (i.e., vehicle speed) and temperature dependent. The viscoelasticity and temperature dependency of the asphalt mixtures shall be indirectly accounted for while calculating the layer coefficients (a_i). This will be accomplished by first calculating 'equivalent' modulus of the asphalt layers from the dynamic modulus (|E*|) mastercurve, which will be predicted using the Hirsch model. This 'equivalent' modulus will be used to calculate the layer coefficients. The following steps should be used to determine the layer coefficients as a function of climate and traffic speed.

Steps of calculating 'equivalent' modulus and layer coefficients of asphalt concrete courses:

Step - 1: Start with an estimated preliminary layer structure and select initial lift thicknesses for the asphalt concrete wearing and base courses and create sublayers (based on lifts) as illustrated in Figure 10.1.1. The steps described herein will be repeated and the number of sublayers (i.e., lifts) and their thicknesses will be adjusted until the Structural Number (SN) produces the required ESAL according to the Equation [10.1.1].

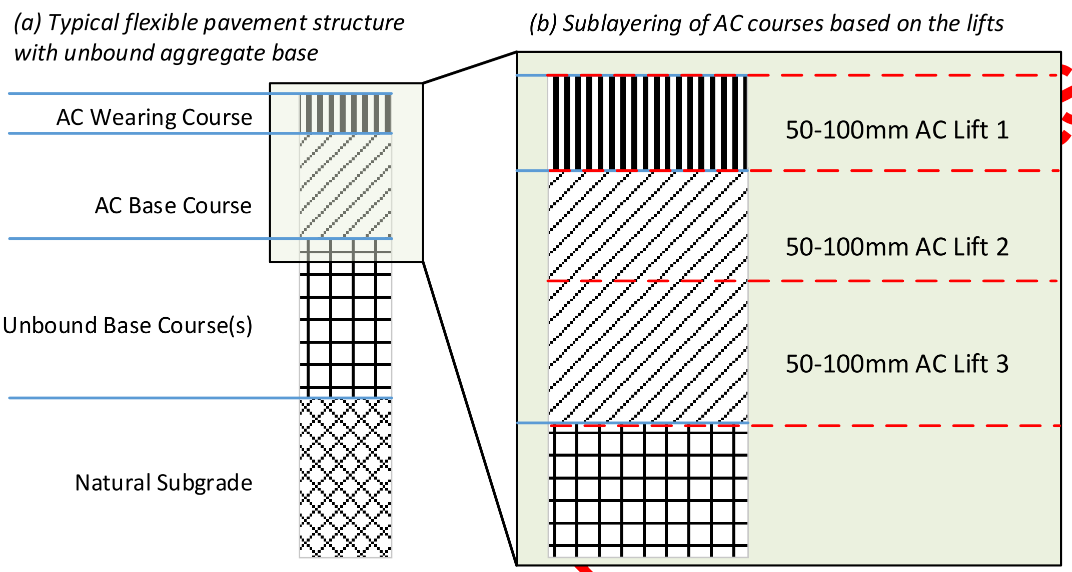


Figure 10.1.1: Example sub-layering of AC courses based on the lifts

Step - 2: Obtain average monthly air temperature profile for the design location for one year. If data for multiple years are available, take the average monthly temperature across multiple years and list the standard deviation. If temperature records are not available, the temperature profiles given in Appendix 101B for the weather station closest to the project location should be used.

Step 3: Estimate the maximum and minimum daily pavement surface temperature using the following formulation (Huber 1994):

$$T_{s(\max)} = T_{\text{air}(\max)} - 0.000618\,Lat^2 + 0.2289\,Lat + 24.4 \quad [10.1.2]$$

$$T_{s(\min)} = 0.859\,T_{\text{air}(\min)} + 1.7 \quad [10.1.3]$$

where:

$T_{s(\max)}$ = maximum pavement surface temperature (^{o}C)

$T_{\text{air}(\max)}$ = maximum air temperature (^{o}C)

Lat = latitude of the location of the pavement

$T_{s(\min)}$ = minimum pavement surface temperature (^{o}C)

$T_{\text{air}(\min)}$ = minimum air temperature (^{o}C)

Step 4: Calculate the average surface temperature from the maximum and minimum temperatures calculated in Step 3 above.

$$T_{s(avg)} = \frac{T_{s(min)} + T_{s(max)}}{2} \qquad [10.1.4]$$

Step 5: From the average surface temperature calculated in step 4 above, calculate the pavement temperature at the center of each layer for each month using the BELLS2 model given in the following equation:

$$\begin{aligned} T_z &= 2.78 + 0.912 T_{s(avg)} \\ &+ \left[\log_{10}(z) - 1.25\right]\left[-0.428(z) + 0.553(1-day) + 2.63\sin(hr_{18} - 15.5)\right] \\ &+ 0.027(z)\sin(hr_{18} - 13.5) \end{aligned} \qquad [10.1.5]$$

where

T_z = Pavement temperature at depth z, ˚C

$T_{s(avg)}$ = Surface temperature, ˚C

z = Depth at which material temperature to be predicted, mm

$1-day$ = Average air temperature on the day before, ˚C (use average monthly temperature when the average air temperature on the day before is not available)

sin = Sine function on an 18-hr clock system, with 2π radians equal to one 18-hour cycle

hr_{18} = Time of day light, in 24-hr system, but calculated using an 18-hr asphalt concrete (AC) temperature sun rise and fall time cycle.

Step 6: Calculate the equivalent loading frequency from the average vehicle speed using the following formula (Losa and Di Natale 2012):

$$f = 0.043 \frac{V}{2a} e^{-2.65z + \beta(T)} \qquad [10.1.6]$$

where

f = Frequency in Hz

V = Vehicle speed (m/s)

a = Radius of tire pressure (m)

z = Distance from surface to the center of the AC sublayer (m)

$$\beta(T) = 1.25 \times 10^{-5} T^3 - 1.6 \times 10^{-3} T^2 + 9.2 \times 10^{-2} T \qquad [10.1.7]$$

where T = average pavement temperature (in ^{o}C).

Step 7: Perform laboratory frequency sweep Dynamic Shear Modulus (|G*|) tests using a Dynamic Shear Rheometer (DSR) on representative asphalt binder samples that are expected to be used in the pavement being designed. The |G*| tests shall be conducted in accordance with AASHTO T315 "Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)" on Rolling Thin Film Oven (RTFO) aged residue. Frequency sweep tests shall be conducted at temperatures of 15, 30, 46, 60 and 76 degrees C. At each temperature, tests shall be run at 11 frequencies varying between 1.0 and 100.0

rad/sec. Three replicate asphalt binder samples shall be tested at each temperature and frequency. The average of the 3 replicates is used to develop the |G*| master curve.

At the preliminary design stage (until |G*| data for the anticipated binder to be used in the construction is available), designer may calculate |G*| values for the temperature and frequency calculated above from typical |G*| master curves of binders similar to those used in Qatar, which are included in Appendix 101C. Appendix 101C also provides step by step description of obtaining |G*| values from |G*| master curve coefficients.

Step 8: From the |G*| master curve developed in the previous step, obtain individual |G*| values corresponding to the temperatures and the loading frequency calculated in the previous steps, then use these values in the Hirsch model to calculate the |E*| values of the asphalt mixture using the following formula:

$$|E^*|_m = P_c\left[4,200,000\left(1-\frac{VMA}{100}\right)+3|G^*|_b\left(\frac{VFA*VMA}{10,000}\right)\right] + \frac{\left(1-P_c\right)}{\frac{\left(1-VMA/100\right)}{4,200,000}+\frac{VMA}{3|G^*|_b\left(VFA\right)}} \quad [10.1.8]$$

$$P_c = \frac{\left(20+3|G^*|_b\left(VFA\right)/\left(VMA\right)\right)^{0.58}}{650+\left(3|G^*|_b\left(VFA\right)/\left(VMA\right)\right)^{0.58}} \quad [10.1.9]$$

where

$\lvert E^*\rvert_m$	=	Dynamic modulus of HMA (psi).
$\lvert G^*\rvert_b$	=	Dynamic shear modulus of binder (psi).
VMA	=	Voids in mineral aggregate
VFA	=	Voids filled with asphalt

Typical VMA and VFA values used in the state of Qatar are listed in Appendix 101D.

Step 9: Use the following relation to convert the modulus computed in the previous step ($|E^*|_m$) to layer coefficient a_1 for the AC layers using the following formula (AASHTO (1993)):

$$a_1 = 0.171*\ln(|E^*|_m) - 1.784 \quad [10.1.10]$$

where

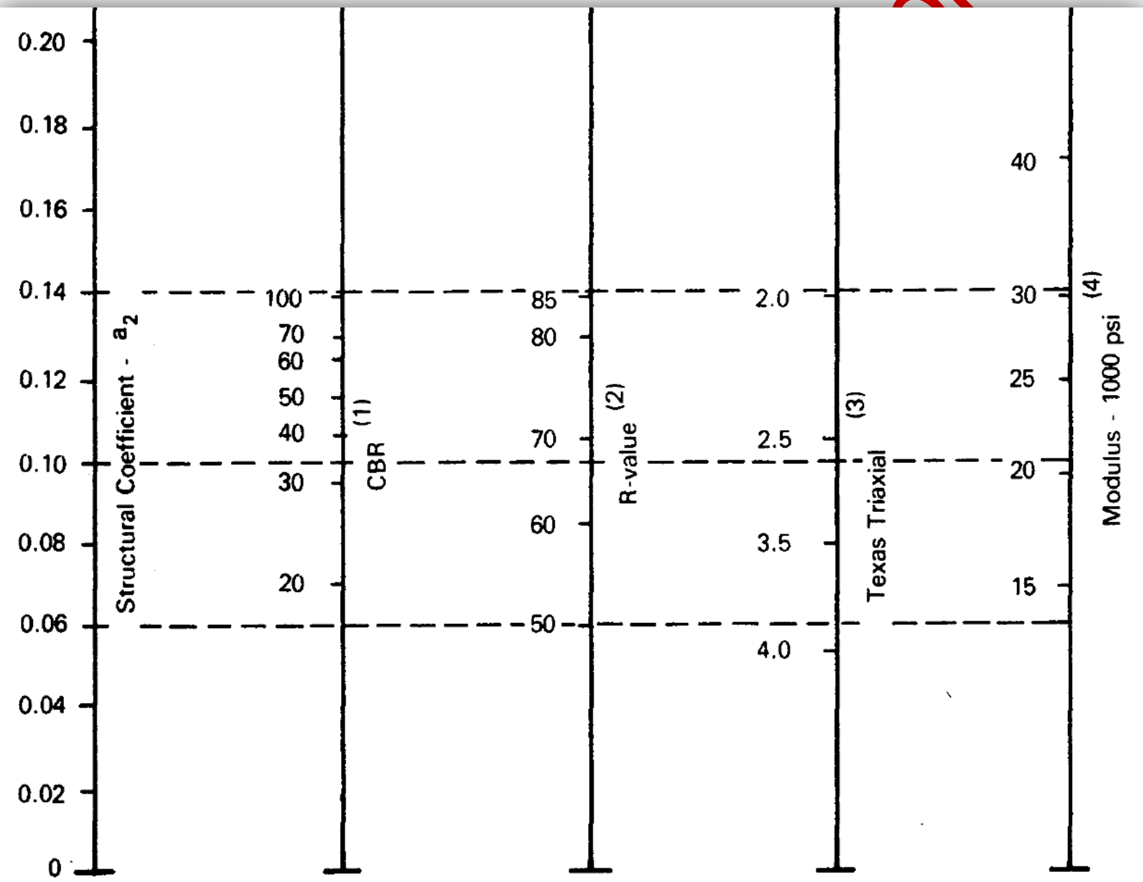
$\lvert E^*\rvert_m$	=	Dynamic modulus of HMA (psi).
a_1	=	Layer coefficient for the AC sublayer.

Step 10: Calculate the layer coefficients for each month for each sublayer. Then, calculate the yearly average of the coefficients for each sublayer and use in the design.

10.1.2 Layer Coefficients (a_i) for Base, Subbase and Cement Bound Materials

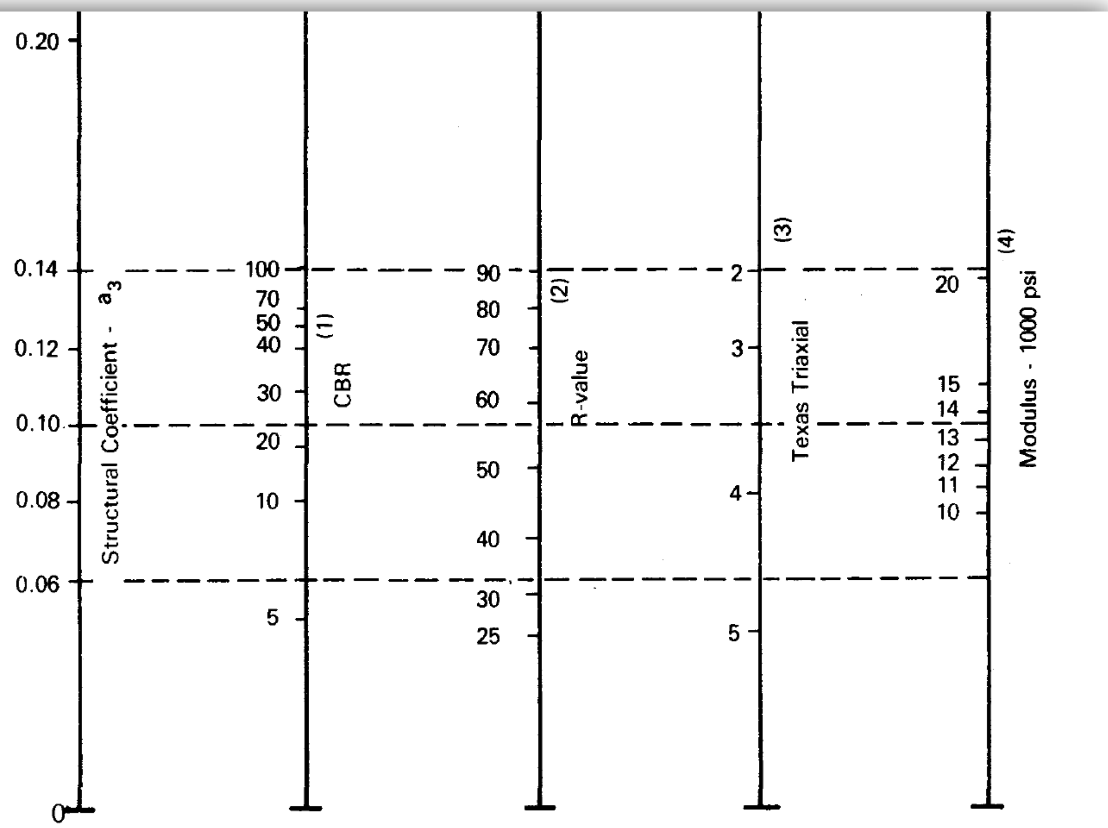
As per QCS 2014, minimum CBR required for the base and subbase are 80% and 70%, respectively. However, the designer can propose materials with higher CBR values. The layer coefficients for the base and subbase shall be obtained using the charts given in Figure 2.6 and Figure 2.7 the AASHTO 1993 Guide. These charts are provided below for convenience (Reference: AASHTO (1993)).

In accordance with the IAN 100, the minimum 7 days cube strength of cement bound materials (CBMs) shall be between 1 to 2.1 MPa. For such materials, use a layer coefficient of 0.16 in AASHTO 1993 design procedure. This value is proposed as a slight modification of the unbound subbase coefficient to account for the increase in strength due to the cement added. CBM with higher strength values are not considered in this design procedure due the high risk of cracking that will be reflected in the surface layers (See references: IS537 (2003) and EB052 (1992)).



(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(3)*.

Figure 2.6. Variation in Granular Base Layer Coefficient (a_2) with Various Base Strength Parameters (3)



(1) Scale derived from correlations from Illinois.

(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming.

(3) Scale derived from correlations obtained from Texas.

(4) Scale derived on NCHRP project *(3)*.

Figure 2.7. Variation in Granular Subbase Layer Coefficient (a_3) with Various Subbase Strength Parameters (*3*)

9. Appendix 101A References

1 AASHTO (1993). AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials, AASHTO, Washington D.C., USA.

2 EB052 (1992) Soil-Cement Laboratory Handbook, Portland Cement Association, Skokie, IL

3 Environment Statistics Annual Report (2013), Ministry of Development Planning and Statistics, State of Qatar.

4 Heukelom, W. and A. J. G. Klomp, “Dynamic Testing as a Means of Controlling Pavements During and After Construction.” Proceedings International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, Michigan (1962) pp. 667-679.

5 Huber, G.A., Weather Database for the Superpave Mix Design System, Strategic Highway Research Program, National Research Council, Washington DC, 1994.

6 IS537 (2003) Reflective Cracking in Cement Stabilized Pavements, Portland Cement Association, Skokie, IL,

7 Losa, M. and Di Natale, A. (2012) “Evaluation of Representative Loading Frequency for Linear Elastic Analysis of Asphalt Pavements” Transportation Research Record: Journal of the Transportation Research Board, No. 2305, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 150–161. DOI: 10.3141/2305-16

8 Maher, A. and Bennert, T. (2008). Evaluation of Poisson’s Ratio for Use in the Mechanistic Empirical Pavement Design Guide (MEPDG). Federal Highway Administration (FHWA) report no FHWA-NJ-2008-004.

9 NCHRP Project 1-37A Report (2004). Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Final Report. National Cooperative Highway Research Program (NCHRP), Washington, D.C.

10 Qatar Construction Specifications - QCS 2014.

11 Qatar Highway Design Manual - QHDM.

12 Sadek, H., Masad, E., Sirin, O., Al-Khalid, H. and Hassan, Khaled (2014) “Performance Evaluation of Full-Scale Sections of Asphalt Pavements in the State of Qatar*”, Journal of Performance of Constructed Facilities, DOI: 10.1061/(ASCE)CF.1943-5509.0000627.*

10. Appendix 101B Typical Annual Temperature Profiles in the State of Qatar

Monthly air temperature profiles for different regions are shown in Table 9B.1. Figure 9B.1 shows the regions where the temperature profile data was collected

Table 101B - 1 Monthly air temperature profiles for different regions in the State of Qatar

(Reference: Environment Statistics Annual Report (2013), Ministry of Development Planning and Statistics, State of Qatar.)

Station	℃	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Doha International Airport (2012)	Min	14.3	15.2	17.4	23.4	30.1	31.2	32.8	32.9	30.6	27.7	23.2	18.6
	Avg	**18.4**	**19.1**	**22.1**	**28.0**	**35.8**	**37.1**	**38.1**	**37.4**	**35.1**	**31.9**	**26.7**	**22.0**
	Max	22.5	22.9	26.8	32.6	41.5	43.0	43.3	41.9	39.6	36.1	30.2	25.3
Al Karanaaha (2012)	Min	10.6	11.6	14.3	20.6	26.5	27.4	29.3	29.2	26.3	22.6	18.7	14.6
	Avg	**16.4**	**17.5**	**20.8**	**27.2**	**34.6**	**35.5**	**37.3**	**36.8**	**33.8**	**29.7**	**24.1**	**19.5**
	Max	22.2	23.3	27.2	33.7	42.6	43.6	45.3	44.3	41.3	36.8	29.5	24.3
Dukhan (2012)	Min	13.4	14.2	16.6	21.1	27.7	28.3	30.3	30.1	28.0	24.4	21.2	16.9
	Avg	**16.7**	**17.6**	**20.2**	**25.8**	**32.5**	**33.8**	**35.1**	**34.9**	**32.7**	**29.2**	**24.4**	**19.8**
	Max	20.0	21.0	23.7	30.5	37.3	39.2	39.9	39.7	37.4	33.9	27.6	22.6
Al Ruwais (2012)	Min	15.2	15.5	17.2	22.3	28.4	29.6	31.1	31.0	29.8	26.1	22.8	14.2
	Avg	**17.8**	**22.7**	**20.2**	**25.1**	**31.7**	**32.3**	**34.2**	**34.3**	**32.5**	**29.5**	**25.2**	**18.5**
	Max	20.3	29.9	23.1	27.9	34.9	35.0	37.3	37.5	35.2	32.9	27.5	22.8
Ummsaid (2012)	Min	11.7	13.3	15.9	21.7	27.1	27.3	29.8	29.9	27.0	24.5	20.4	15.7
	Avg	**16.9**	**18.0**	**21.1**	**26.8**	**33.8**	**34.9**	**36.0**	**35.6**	**33.3**	**29.8**	**25.2**	**20.3**
	Max	22.0	22.6	26.3	31.9	40.5	42.4	42.2	41.3	39.5	35.0	29.9	24.9

Figure 101B - 1: Regions where the temperature profile data was collected (Reference: Environment Statistics Annual Report (2013), Ministry of Development Planning and Statistics, State of Qatar.)

11. Appendix 101C Typical Asphalt Binder |G*| Master Curves used in the State of Qatar

Table 101C-1 shows the |G*| master curve coefficients of typical binders used in the State of Qatar. In order to determine the |G*| and binder phase angle values at any temperature and frequency, the following basic steps are followed:

- Step 1: Calculate the shift factor coefficient a(T) using the following equation described earlier: $\log(a(\mathrm{T})) = \mathrm{a}_1(\mathrm{T}^2 - \mathrm{T}_{\mathrm{ref}}^2) + \mathrm{a}_2(\mathrm{T} - \mathrm{T}_{\mathrm{ref}})$. Note T_{ref} = 21°C for the binders in
- Step 2: Calculate the reduced frequency from the frequency of the traffic load: $f_R = f\ a(T)$
- Step 3: Calculate the |G*|: $\log(|G^*|) = b_1 + \frac{b_2}{1 + \exp(-b_3 - b_4 \log(f_R))}$

Table 101C - 1: |G*| master curve coefficients of typical binders similar to those used in the State of Qatar. These coefficients will produce |G*| in Pascals (Pa)

Binder PG	a1	a2	b1	b2	b3	b4
PG64-22	0.000664	-0.145	-1.509	9.807	1.300	0.330
PG76-16	0.000864	-0.155	0.072	8.034	1.316	0.356

12. Appendix 101D Typical volumetrics of asphalt mixtures used in the State of Qatar

Table 101E - 1: Typical volumetrics of asphalt mixtures used in the State of Qatar*

Layer	Binder type	NMAS	VMA	VFA	Va	Pb	P0.075
ASC	60/70pen	19	14.9-16.9	54.7-63	5.2-7.4	3.5-4.2	3.2-4.8
ASC	PMB	19	14.9-16.7	57.3-67	5-6.5	4.3-4.5	3.4-5.3
AIC	60/70pen	19	14.5-16.4	55-62	4.9-7.1	3.6-3.8	3.6-4.9
ABC	60/70pen	25	13.7-16.5	53.8-65	4.9-7.6	3.4-3.7	3.4-4.9
ABC	60/70pen	19	14.9-15	64.5-66.6	5-5.3	4.3-4.4	3.6-4.9
ABC	PMB	25	-	-	-	-	-
ABC	PMB	19	15.2-17.4	58.6-67	5-7.2	3.9-4.6	4-4.7

*The data is based on ANAS monitoring effort for the past two years.

13. Appendix 101E ESAL Factor Calculations

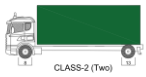
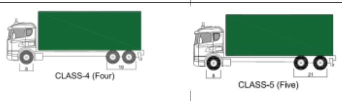
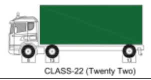
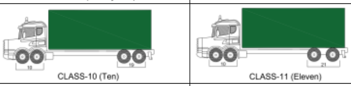
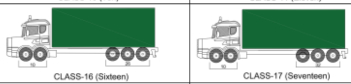
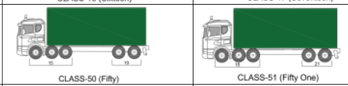
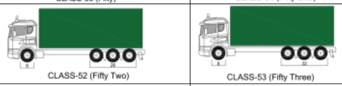
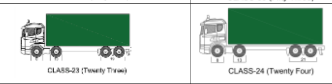
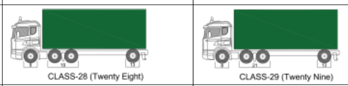
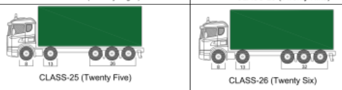
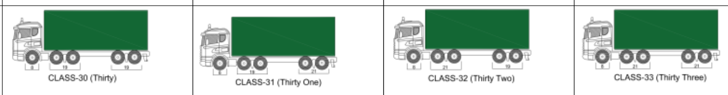
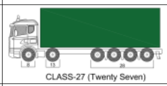
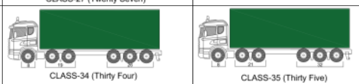
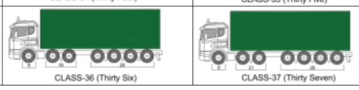
Table 101E - 1. ESAL Calculations Using 90th Percentile Gross Vehicle Weight (GVW) Data Obtained from WIM Stations in Qatar

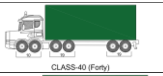
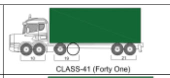
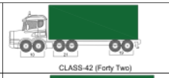
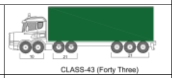
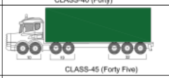
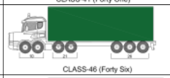
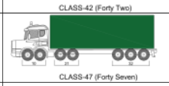
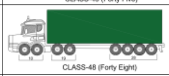
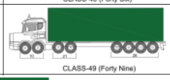
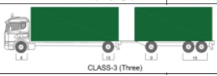
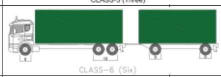
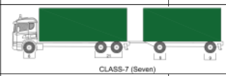
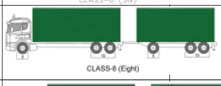
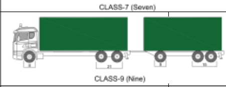
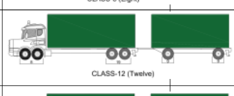
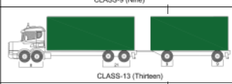
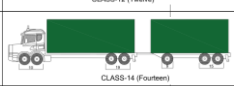
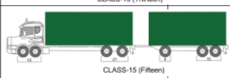
Type	Axle Config.	GCC Truck Classification	Total ESAL Factor	GVW (tons) 90th Percentile	Weight for Each Axle Load/Group (Tons)											ESAL Factor for Each Axle Load/Group										
					Steer			Drive			Trailer					Steer			Drive			Trailer				
					1	2	3	1	2	3	1	1	2	3	4	1	2	3	1	2	3	1	1	2	3	4
2 Axle 6 Tire Rigid	11	2	0.54	11.2	4.3	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.069	0.000	0.000	0.469	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3 Axle Rigid	12	4,5	1.13	20.7	5.9	0.0	0.0	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.252	0.000	0.000	0.000	0.874	0.000	0.000	0.000	0.000	0.000	0.000
3 Axle Articulated	111	22	0.04	7.9	1.9	0.0	0.0	3.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.003	0.000	0.000	0.017	0.000	0.000	0.017	0.000	0.000	0.000	0.000
4 or more Axle Rigid	22	10, 11	2.05	27.2	0.0	9.1	0.0	0.0	18.1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.128	0.000	0.000	1.926	0.000	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	23	16, 17	0.74	26.7	0.0	6.9	0.0	0.0	0.0	19.9	0.0	0.0	0.0	0.0	0.0	0.000	0.043	0.000	0.000	0.000	0.694	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	32	50, 51	0.53	22.4	0.0	0.0	9.6	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.039	0.000	0.492	0.000	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	13	52, 53	0.38	20.5	4.4	0.0	0.0	0.0	0.0	16.1	0.0	0.0	0.0	0.0	0.0	0.080	0.000	0.000	0.000	0.000	0.299	0.000	0.000	0.000	0.000	0.000
4 or less Axle Articulated	112	23, 24	0.54	19.9	3.9	0.0	0.0	6.3	0.0	0.0	0.0	0.0	9.7	0.0	0.0	0.047	0.000	0.000	0.322	0.000	0.000	0.000	0.000	0.167	0.000	0.000
4 or less Axle Articulated	121	28, 29	1.03	23.5	4.6	0.0	0.0	0.0	11.4	0.0	7.4	0.0	0.0	0.0	0.0	0.091	0.000	0.000	0.000	0.319	0.000	0.620	0.000	0.000	0.000	0.000
5 Axle Articulated	113	25, 26	0.64	25.3	4.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	0.0	14.7	0.0	0.056	0.000	0.000	0.380	0.000	0.000	0.000	0.000	0.000	0.209	0.000
5 Axle Articulated	122	30, 31, 32, 33	0.50	24.9	4.1	0.0	0.0	0.0	10.4	0.0	0.0	0.0	10.4	0.0	0.0	0.061	0.000	0.000	0.000	0.217	0.000	0.000	0.000	0.217	0.000	0.000
6 or more Axle Articulated	114	27	1.06	30.1	4.9	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	17.2	0.119	0.000	0.000	0.817	0.000	0.000	0.000	0.000	0.000	0.000	0.125
6 or more Axle Articulated	123	34, 35	0.40	27.9	3.9	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	14.2	0.0	0.049	0.000	0.000	0.000	0.173	0.000	0.000	0.000	0.000	0.183	0.000
6 or more Axle Articulated	124	36, 37	0.43	30.7	4.4	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	15.4	0.077	0.000	0.000	0.000	0.271	0.000	0.000	0.000	0.000	0.000	0.081
6 or more Axle Articulated	222	40, 41, 42, 43	0.26	22.6	0.0	4.5	0.0	0.0	9.0	0.0	0.0	0.0	9.0	0.0	0.0	0.000	0.008	0.000	0.000	0.126	0.000	0.000	0.000	0.126	0.000	0.000
6 or more Axle Articulated	223	45, 46, 47	0.42	29.7	0.0	4.9	0.0	0.0	10.2	0.0	0.0	0.0	0.0	14.6	0.0	0.000	0.011	0.000	0.000	0.205	0.000	0.000	0.000	0.000	0.206	0.000
6 or more Axle Articulated	224	48, 49	0.15	25.2	0.0	4.3	0.0	0.0	8.7	0.0	0.0	0.0	0.0	0.0	12.2	0.000	0.007	0.000	0.000	0.109	0.000	0.000	0.000	0.000	0.000	0.032
Rigid Truck + Trailer	1112	3	1.27	27.6	4.9	0.0	0.0	8.0	0.0	0.0	5.5	0.0	9.2	0.0	0.0	0.120	0.000	0.000	0.821	0.000	0.000	0.191	0.000	0.137	0.000	0.000
Rigid Truck + Trailer	1211	6,7	0.69	26.2	4.6	0.0	0.0	0.0	11.4	0.0	5.1	5.1	0.0	0.0	0.0	0.089	0.000	0.000	0.000	0.314	0.000	0.143	0.143	0.000	0.000	0.000
Rigid Truck + Trailer	1212	8,9	0.43	26.6	4.1	0.0	0.0	0.0	10.2	0.0	4.6	0.0	7.7	0.0	0.0	0.058	0.000	0.000	0.000	0.207	0.000	0.093	0.000	0.067	0.000	0.000
Rigid Truck + Trailer	2211	12,13	0.86	28.7	0.0	5.0	0.0	0.0	12.5	0.0	5.6	5.6	0.0	0.0	0.0	0.000	0.012	0.000	0.000	0.445	0.000	0.203	0.203	0.000	0.000	0.000
Rigid Truck + Trailer	2212	14,15	0.33	26.6	0.0	4.9	0.0	0.0	9.9	0.0	4.4	0.0	7.4	0.0	0.0	0.000	0.012	0.000	0.000	0.178	0.000	0.080	0.000	0.058	0.000	0.000

Table 101E - 2. ESAL Calculations Using the Maximum Allowable Gross Vehicle Weight (GVW) for Each Truck

Type	Axle Config.	GCC Truck Classification	Total ESAL Factor	Max. Legal Load (Tons)	Weight for Each Axle Load/Group (Tons)											ESAL Factor for Each Axle Load/Group										
					Steer			Drive			Trailer					Steer			Drive			Trailer				
					1	2	3	1	2	3	1	1	2	3	4	1	2	3	1	2	3	1	1	2	3	4
2 Axle 6 Tire Rigid	11	2	**6.49**	**21.0**	8.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.827	0.000	0.000	5.661	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3 Axle Rigid	12	4,5	**3.65**	**28.0**	8.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	0.000	0.000	0.000	0.000	0.000
3 Axle Articulated	111	22	**12.15**	**34.0**	8.0	0.0	0.0	13.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.827	0.000	0.000	5.661	0.000	0.000	5.661	0.000	0.000	0.000	0.000
4 or more Axle Rigid	22	10, 11	**3.01**	**30.0**	0.0	10.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.188	0.000	0.000	2.822	0.000	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	23	16, 17	**3.25**	**39.0**	0.0	10.0	0.0	0.0	0.0	29.0	0.0	0.0	0.0	0.0	0.0	0.000	0.188	0.000	0.000	0.000	3.058	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	32	50, 51	**3.05**	**35.0**	0.0	0.0	15.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.228	0.000	2.822	0.000	0.000	0.000	0.000	0.000	0.000
4 or more Axle Rigid	13	52, 53	**3.89**	**37.0**	8.0	0.0	0.0	0.0	0.0	29.0	0.0	0.0	0.0	0.0	0.0	0.827	0.000	0.000	0.000	0.000	3.058	0.000	0.000	0.000	0.000	0.000
4 or less Axle Articulated	112	23, 24	**9.31**	**41.0**	8.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.827	0.000	0.000	5.661	0.000	0.000	0.000	0.000	2.822	0.000	0.000
4 or less Axle Articulated	121	28, 29	**9.31**	**41.0**	8.0	0.0	0.0	0.0	20.0	0.0	13.0	0.0	0.0	0.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	5.661	0.000	0.000	0.000	0.000
5 Axle Articulated	113	25, 26	**9.55**	**50.0**	8.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	29.0	0.0	0.827	0.000	0.000	5.661	0.000	0.000	0.000	0.000	0.000	3.058	0.000
5 Axle Articulated	122	30, 31, 32, 33	**6.47**	**48.0**	8.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	20.0	0.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	0.000	0.000	2.822	0.000	0.000
6 or more Axle Articulated	114	27	**7.35**	**49.0**	8.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.827	0.000	0.000	5.661	0.000	0.000	0.000	0.000	0.000	0.000	0.859
6 or more Axle Articulated	123	34, 35	**6.71**	**57.0**	8.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	29.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	0.000	0.000	0.000	3.058	0.000
6 or more Axle Articulated	124	36, 37	**4.51**	**56.0**	8.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	28.0	0.827	0.000	0.000	0.000	2.822	0.000	0.000	0.000	0.000	0.000	0.859
6 or more Axle Articulated	222	40, 41, 42, 43	**5.83**	**50.0**	0.0	10.0	0.0	0.0	20.0	0.0	0.0	0.0	20.0	0.0	0.0	0.000	0.188	0.000	0.000	2.822	0.000	0.000	0.000	2.822	0.000	0.000
6 or more Axle Articulated	223	45, 46, 47	**7.10**	**61.0**	0.0	10.0	0.0	0.0	21.0	0.0	0.0	0.0	0.0	30.0	0.0	0.000	0.188	0.000	0.000	3.414	0.000	0.000	0.000	0.000	3.495	0.000
6 or more Axle Articulated	224	48, 49	**3.87**	**58.0**	0.0	10.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	28.0	0.000	0.188	0.000	0.000	2.822	0.000	0.000	0.000	0.000	0.000	0.859
Rigid Truck + Trailer	1112	3	**8.72**	**45.0**	8.0	0.0	0.0	13.0	0.0	0.0	9.0	0.0	15.0	0.0	0.0	0.827	0.000	0.000	5.661	0.000	0.000	1.319	0.000	0.917	0.000	0.000
Rigid Truck + Trailer	1211	6,7	**6.29**	**46.0**	8.0	0.0	0.0	0.0	20.0	0.0	9.0	9.0	0.0	0.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	1.319	1.319	0.000	0.000	0.000
Rigid Truck + Trailer	1212	8,9	**5.88**	**52.0**	8.0	0.0	0.0	0.0	20.0	0.0	9.0	0.0	15.0	0.0	0.0	0.827	0.000	0.000	0.000	2.822	0.000	1.319	0.000	0.917	0.000	0.000
Rigid Truck + Trailer	2211	12,13	**5.54**	**46.0**	0.0	8.0	0.0	0.0	20.0	0.0	9.0	9.0	0.0	0.0	0.0	0.000	0.079	0.000	0.000	2.822	0.000	1.319	1.319	0.000	0.000	0.000
Rigid Truck + Trailer	2212	14,15	**5.25**	**54.0**	0.0	10.0	0.0	0.0	20.0	0.0	9.0	0.0	15.0	0.0	0.0	0.000	0.188	0.000	0.000	2.822	0.000	1.319	0.000	0.917	0.000	0.000

14. Appendix 101F Vehicle Class Images

Class	Type	Axle Config.	GCC Truck Classification	QHDM Classification	Truck Images
C1	RT	11	2	5, 6	
C2	RT	12	4,5	-	
C3	AT	111	22	7, 8	
C4	RT	22	10, 11	-	
C5	RT	23	16, 17	-	
C6	RT	32	50, 51	-	
C7	RT	13	52, 53	-	
C8	AT	112	23, 24	9	
C9	AT	121	28, 29	11	
C10	AT	113	25, 26	10	
C11	AT	122	30, 31, 32, 33	12	
C12	AT	114	27	-	
C13	AT	123	34, 35	13	
C14	AT	124	36, 37	-	

Type	Class	Type	Axle Config.	GCC Truck Classification	QHDM Classification	Images			
6 or more Axle Articulated	C15	AT	222	40, 41, 42, 43	-				
6 or more Axle Articulated	C16	AT	223	45, 46, 47	-				
6 or more Axle Articulated	C17	AT	224	48, 49	-				
Rigid Truck + Trailer	C18	RT+T	1112	3	5+14				
Rigid Truck + Trailer	C19	RT+T	1211	6,7	-				
Rigid Truck + Trailer	C20	RT+T	1212	8,9	-				
Rigid Truck + Trailer	C21	RT+T	2211	12,13	-				
Rigid Truck + Trailer	C22	RT+T	2212	14,15	-				
Light Goods Vehicle	C23	LGV	11	2	5				
Medium Bus	C24	M. Bus	11	2	3,4				
Large Bus	C25	L. Bus	11