Clarification about different versions of analysis tools for the Linear Amplitude Sweep (LAS) Test

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Introduction

The AASHTO standard for the LAS procedure was first introduced in 2012 by the MARC researchers as a product of the Asphalt Research Consortium (ARC) project, funded by the FHWA. The provisional standard was numbered AASHTO TP101-12 and to facilitate the analysis of test results, a spreadsheet was created and posted on MARC website. The TP101-12 version included a stepped linear strain procedure and used the dissipated energy equation in which the G*sinδ was used. It also included the damage criterion of 35% damage for the analysis. In 2014, the AASHTO standard was changed to a new version (AASHTO TP101-14) in which the strain application was changed to a linear ramp, the pseudo stiffness C was used (only G* included in the dissipated energy calculation) and the damage criterion was changed to the peak of the stress values. These changes resulted in modifications of the spreadsheet posted on the MARC website. The different versions of MARC spreadsheet, although intended to follow the AASHTO changes, resulted in some confusion. In 2021 AASHTO converted the provisional standard TP 101 into a permanent standard AASHTO T391 in which the original procedure and analysis that was in the TP 101-12 was basically repeated and the changes implemented in the TP101-14 were revised back to the original procedure. For the record, MARC active staff was not involved in any of these changes. This technical report is to explain the differences between the procedures and explain the reason for using the T391 as a final recommended procedure. The spreadsheets posted on MARC web site will be all removed and only one version following the T391 (v1.57) will be made accessible.

Comparison of the LAS Procedures

The following table include the comparison of the details of the different procedures.

Table 1 Comparison between two versions of LAS specifications

Differences	AASHTO T391/ AASHTO TP101-12	AASHTO TP101-14
Loading mode	Step	Linear continuous
α (Note: B=-2α)	$1+\frac{1}{m}$	$\frac{1}{m}$
Work performed W	Pseudo dissipated energy: $W = \pi I_D \gamma_i^2 G_i^* sin\delta_i$	Simplification and normalization: $W = \pi C_i \gamma_i^2$
Damage calculation $D(t)$	$D(t) = \sum \left[\pi I_D \gamma_i^2 (G_i^* sin\delta_i - G_{i-1}^* sin\delta_{i-1})^{\frac{\alpha}{1+\alpha}} (t_i - t_{i-1})^{\frac{1}{1+\alpha}}\right]$	$D(t) = \sum \left[\pi \gamma_i^2 (C_i - C_{i-1})^{\frac{\alpha}{1+\alpha}} (t_i - t_{i-1})^{\frac{1}{1+\alpha}}\right]$
C_0	Average value of $\lvert G_i^* \rvert sin\gamma$ in 0.1% strain interval	1
Failure criteria D_f	35% reduction in undamaged C_0	The reduction in initial $\lvert G_i^* \rvert$at peak shear stress
A	$\frac{f(D_f)^k}{k(\pi I_D C_1 C_2)^\alpha}$	$\frac{f(D_f)^k}{k(\pi C_1 C_2)^\alpha}$
Others	I_D = initial value of $\lvert G_i^* \rvert$from 1% strain interval, MPa	$C(t) = \frac{\lvert G_i^* \rvert (t)}{\lvert G_i^* \rvert_{initial}}$

The purpose of this Excel spreadsheet update (v1.57) is to update the previous versions and follow the newest procedure in AASHTO T391.

To explain this update, the differences between the two versions listed in Table 1 are explained in the following points.

(a) Loading Mode

Compared to linear continuous mode, step mode allows stabilizing the strain applied, which is required to measure accurately the mechanical response during each interval, especially in the first interval under 0.1% applied strain for the precise determination of C_0. In addition, using the linear strain procedure cannot be achieved by all DSRs in which stress is controlled. In such DSRs, the linear strain ramp is seen significantly distorted. It should also be mentioned that some DSRs may have difficulty controlling the applied strain precisely following the pre-set interval in the stage of sudden strain change from one step to the next. In summary, the stepped strain ramp is what is recommended as it gives better control on the strain ramping and allows better determination of the C_0.

(b) α parameter

Researchers who focused on formulating the value of α found that when α is taken to 1+1/m, it presents a better fitting prediction to practical strain-control test results, while in stress-control test, using α as equal to 1/m gave better fitting. Therefore, since the LAS is a strain-controlled test, using the value of α equals to 1+1/m is recommended, as listed in the T391.

(c) Work parameter W

In AASHTO TP101-14(2014), the "C" parameter was introduced as a normalized modulus values instead of the absolute values (G*) that simplifies the formulation and comparisons. But it seems to be more reasonable to consider the phase angle δ in calculation of W as shown in the AASHTO T391 because sufficient data show that phase angle is changing with damage for the viscoelastic material. This change in phase angel cannot be ignored.

(d) Failure criteria D_f

The value of $D(t)$ at failure, D_f, is defined as the $D(t)$ which corresponds to a 35% reduction in undamaged $|G^*|sin\delta$ (refers to C_0) as specified in T391, while it is defined as the $D(t)$ at the peak stress value. Some research shows that modified asphalts have the capacity to further resist fatigue after the 35% damage and thus it is inaccurate to apply the 35% failure criterion for some types of modified asphalts. However, to be on the safe side allowing more damage than 35% could be too risky. Therefore, the new version of the analysis spreadsheet follows the 35% damage as listed in the T391 standard.

Examples of Results

To explain the magnitude of the differences, one unmodified binder and one modified binder were tested in one rheometer using both AASHTO procedures with step and linear strain ramping. Figure 1 shows the strain ramps for the two binders and as can be noticed, using the continuous linear ramping results in distortion of the strain ramps.

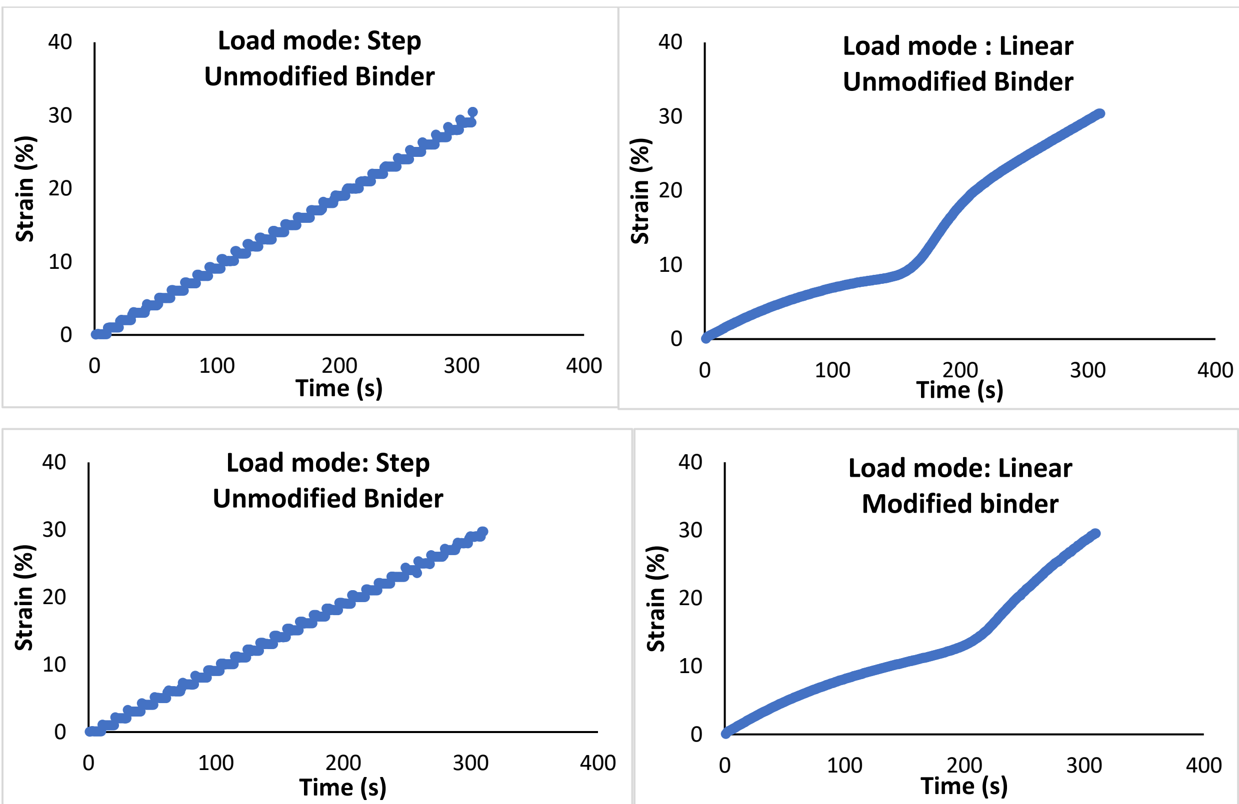

Figure 1: Strain Ramping results for unmodified and modified binders.

Table 2 includes the analysis results for all tests conducted following the two procedures. The results show that changing the strain ramping mode has only marginal effects as compared to changing the test procedure (AASHTO T395 and AASHTO TP101-14). As a result, the A value determined from the T391 is much higher than the value determined from the T101-14. Although there are significant difference in NF values, it is important to note that the modified asphalt consistently show better fatigue resistance than the unmodified binder, with the exception of the results of using the TP101-14 at 15% strain. If the modified binders are expected to perform better, then using the T391 results are more logical.

Table 1. Results of analysis of different LAS procedures.

Standard Followed	Load mode	Asphalt binder	initial θ	initial G*	Slope	α	Co	C1	C2	Df	A	B	Nf-2.5%	Nf-5%	Nf-15%
AASHTO T391	step	base asphalt	50.65	5161241	0.67	2.49	3.99	0.14	0.44	691	26362575.5	4.984	273,918	8,655	36
	Linear continous	base asphalt	50.99	5658750	0.68	2.48	4.38	0.12	0.47	742	20061828.7	4.961	212,982	6,840	29
	step	SBS	39.5	8601852	0.49	3.03	5.49	0.21	0.38	1,879	940243475.5	6.053	3,668,730	55,257	72
	Linear continous	SBS	39.66	8373490	0.49	3.03	5.31	0.20	0.39	1,687	757140183.9	6.053	2,954,346	44,498	58
AASHTO TP101-14	Linear continous	base asphalt	50.99	5658750	0.68	1.48	1.00	0.09	0.46	39	86453.7	2.961	5,736	737	28
	step	base asphalt	50.65	5161241	0.67	1.49	1.00	0.10	0.44	40	93291.4	2.984	6,058	766	29
	Linear continous	SBS	39.66	8373490	0.49	2.03	1.00	0.17	0.33	48	1455141.1	4.053	35,487	2,138	25
	step	SBS	39.5	8641852	0.49	2.03	1.00	0.17	0.32	43	1127262.2	4.053	27,490	1,656	19