FWD Testing as a Construction Control Tool

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ABSTRACT: Construction control is an important link in the construction process chain. It serves as a quality control means, but also assures that the builder fulfills the contract. Various ways of performing control have evolved over time, many employing statistical methods. Apart from taking samples to be analyzed in the laboratory, field tests are done to check for compaction or density and properties like elastic modulus. The latter could also be utilized in the mechanistic design process to either test, or suggest alterations to, the initial design. In comparing derived moduli from e.g. plate loading tests with Falling Weight Deflectometer (FWD), results have been inconclusive. For one thing the time domain is different, but also the magnitude of the load. The present paper presents some comparative tests with static plate tests with light and heavy FWD data. The latter can produce a similar load to the one exerted by traffic, so that appropriate moduli can be used in the design model. For testing compaction, repeated loading and stress sensitivity analyses can be used, which are described in the paper. For testing on subgrade materials there are some practical problems like accessibility and uneven surfaces that must be coped with if heavier equipment is being used. However, as the data can indeed be used for active design, it is viable to do the testing in spite of the higher costs and loss of data. The active design method could save use of expensive materials.

KEY WORDS: Design life, rutting, deformation, roughness, base, construction control

1 INTRODUCTION

Active design was coined in the 1980:ies as something that could revolutionize conventional road construction. The idea of adjusting layer thickness as demanded by the subgrade and/or finished unbound layers is a staggering thought as presumably much material could be saved. In later years sustainability and the savings of materials in general have gained interest. However, since the idea came up, there are few projects with active design done and the reason seems to be for contractual reasons. The buyer must be certain that the criteria deciding the thickness is reliable; and the contractor will not grant a design that may be closer to failure and risk paying a penalty. In this context, the form of contract where the builder warrants the function of the road for an extended time is more suitable as maintenance and rehabilitation are handled by a solitary operator. The AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG) also lends itself to a wider range of alternatives as long as certain basic criteria are met. The MEPDG is not used in Sweden but the present road design code allows three levels of design, from simple Design Class 1 (DK1) to empirical Design Class 2 (DK2) to advanced denoted Design Class 3, (DK3). The present paper presents how active design has evolved to finally being used for a DK3 project. From discussing what test methods are suitable to what input parameters to use in the active design process.

2 CONSTRUCTION CONTROL TEST METHODS

Many materials tests can be performed on the subgrade and unbound materials, like gradation, moisture content, California Bearing Ration (CBR) et cetera. For testing the mechanical properties the static plate load test (PLT) evolved from first being used in Germany around 1930. Later on, response sensors in rollers have helped to decide when compaction is sufficient. In addition, the light falling weight deflectometer (LWD) has gained in popularity by contractors due to its portability and short set-up time.

2.1 The Plate Load Test

As mentioned above the static plate bearing test has been around for a long time. Originally, it was intended as a foundation test but it now doubles as a surface modulus test and compaction test as well. There is a German standard for performing the test, (DIN 2001). The load is applied. The load history and deformation are registered as to derive a surface modulus Ev_1. The procedure is repeated and hence another modulus is achieved Ev_2. The ratio between the two tests is an indicator of compaction. If the values are practically the same the compaction is indeed good, but in most cases Ev_2 is slightly less than Ev_1. There are many manufacturers of the equipment. A load frame is usually not included. Instead a heavy wheel loader or truck readily available at construction sites is often used.

The former National Swedish Road Administration (NSRA) released a guide for conducting plate load tests, (VVMB 1993). In addition to applying the load, there are aspects on the number of tests needed per area tested by another publication by NSRA, (VVMB 1994). The PLT is perhaps not the most modern and up to date test method there is, but nevertheless it gained some popularity in Sweden rather late last century. The equipment is not expensive so even smaller companies can afford it. The drawback is the long cycle for performing one test. It also ties the vehicle used as a load frame. The slow procedure does not allow for a good statistical representation of the areas tested either.

2.2 The Light Falling Weight Deflectometer

The Light Weight Deflectometer (LWD) has gained acceptance as testing device over the PLT due to its swiftness and easy to use operation. It produces a dynamic load, which is different from a “static” load. The difference between the methods on some materials is large, e.g. asphalt bound materials. For finer soils containing water the results from the PLT may differ considerably. The relatively short pulse is normally producing a much stiffer response than the PLT so the respective surface moduli are not directly comparable. The test is easily repeated so that the compaction of any surface can be tested. The volume soil affected by the load is relatively small compared to the PLT though so in this respect, the LWD may not be the preferred tool. The displacement is measured by geophones and by moving the sensor a deflection basin may be derived. Alternatively, some LWD:s may be equipped with extra sensors to derive the deflection basin in one simultaneous drop. Certainly, preferable if the modulus is changing with the number of drops.

Figure 1: Plate Load Test equipment with jack and data collection unit.

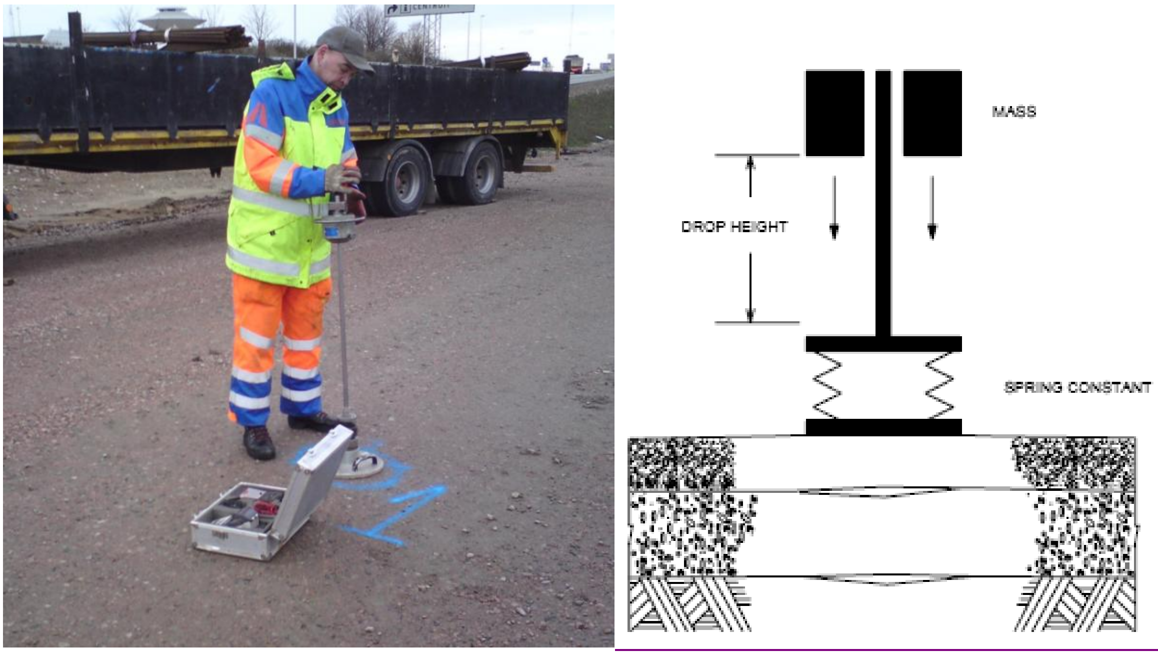

Figure 2: The LWD at a test site and illustration of the load applied.

2.3 Roller response equipment

The roller mounted devices measure the response acceleration of the roller drum. As the input amplitude and frequency are known, the damping of the dynamic pulse can be derived. If there is little damping the idea is that the compaction good. With a Differential Global Positioning System (DGPS), there is also a good record of the whereabouts of the roller. As such this is a very efficient tool for the contractor to optimize the rolling operations. As a construction control tool it is questionable. More so from a regulating standpoint than a technical issue. Could or should any process verify its own performance? There is also an issue whether such systems are optimizing for the roller load and if this is compatible with optimizing for the final traffic load, which undoubtedly will produce the future rutting. However, these aspects are not included in the present paper.

3 COMPARATIVE STUDIES

There have been a number of studies correlating PLT with FWD. Particularly regarding the surface modulus. Some will show a good correlation with no shift in intercept, and those tests are most likely done on elastic materials. E.g. coarse and dry granular materials tested at the same stress magnitude. Other tests do not correlate at all, and the reasons for that are a discrepancy between dynamic and static loading, water present and different stress levels. An interesting attempt to assess PLT subgrade testing on a finished subbase with FWD data was done in southern Sweden in 2006. Persisting precipitation during the fall that year made the subgrade inaccessible for the PLT equipment during construction. The subbase was to be completed before the frost season so the subgrade surface was not tested by mistake. However, by testing with several load levels on the subbase surface with the FWD it was possible to derive a subgrade modulus for the appropriate stress condition using backcalculation. It included adjusting for the static overburden from the subbase layer. By analyzing time histories one could also scrutinize any time dependant effects. Some test points were influenced by water, and those were naturally difficult to recalculate. However, these test points were not passed as good anyway by the testing criteria. The exercise showed though that it is possible to derive PLT data from FWD tests, but impossible to reenact FWD data from a PLT test as there is no clue about the dynamic properties from such an investigation.

With Mechanistic Empirical Design it was suggested from the Regional Western Road Administration in Sweden that the PLT criteria could be used for active design purposes. Typically, instead of passing and failing test points one could introduce a scale of various grades. For instance a previous “fail” could be compensated by a thicker asphalt design. Vice versa a good result could allow for a thinner and more economic design. Thus, the contractor has an incentive to prepare the subgrade and other unbound layers to a higher compaction, so that a more sustainable design is achieved.

Thus, the intention is good, but could a test intended as a production control really serve as a design tool also?

3.1 Testing PLT and LWD as interactive tools good for bearing capacity measurements

A diploma work for a master’s thesis included comparing PLT, LWD and FWD at a road construction site in Malmö, (Hon 2010). The tests took place on the subgrade and unbound base layer as well. The findings concluded that the ways of testing are indeed different. The influenced zone of the LWD is more limited than the others. If the bearing capacity should be assessed with a LWD, one must test for each lift in the process. The primary reason for using an LWD would be checking the compaction of a thin layer only. The influence zone of the PLT is larger, but Hon did not reach better correlation than a coefficient of determination of 0.5. It was then concluded that a full size FWD should be choice for decisions regarding bearing capacity and thus active design.

3.2 Further testing PLT and FWD for active design

The diploma work was a diligent study of the possibilities for employing the PLT and LWD for active design, but the site was limited as there was only one type of soil and also only one type of design. Some more tests were needed to validate Hon’s findings. Another diploma work at Lund was conducted at a construction site were active design was already decided based on FWD testing, (Forsberg & Pinotti, 2012).

Figure 3: Gislaved is located inland about 130 km Southeast of Göteborg.

The site located near Gislaved, in a forested area in Småland in Southern Sweden, was identified as a project suitable for active design by the contractor, see Figure 3. This bypass project consists of a new alignment and widening of an existing two-lane road to a three-lane road. FWD data were provided by the Swedish Transport Administration for the existing part. It showed that the subgrade conditions were good and that the customary DK2 design likely would be more than sufficient as far as bearing capacity goes. The DK2 design called for 135 mm of asphalt bound layers, and the DK3 design showed that 90 mm would be sufficient for at least 67% of the project length. Hence, there was a considerable amount of materials used to be saved. The DK3 design parameters used here is fatigue strain in the asphalt layers and a top of the subgrade strain criterion. The latter is expressed as a rutting rate of 0.8 mm per annum, allowing for a first year initial rutting of 3 mm. Thus, after ten years the rutting will amount to 11 mm maximum. Surface wear from studded tires is controlled by using an appropriately durable aggregate for the surface layer.

As there is some frost in the area, the design was also checked towards the minimum total thickness regarding frost heave. The pavement thickness mitigating frost heave is not material sensitive, so if the 90 mm design were to be used, the remaining 45 mm of asphalt could be substituted for unbound material. The design traffic amounted to about 5 500 000 equivalent axle loads, with some minor variation between interchanges. Prior to construction the existing road was FWD tested again with an extended ten drop sequence and sampled time histories in the summer of 2011. It confirmed the rather stiff subgrade soil and that water was not present, see Figure 4.

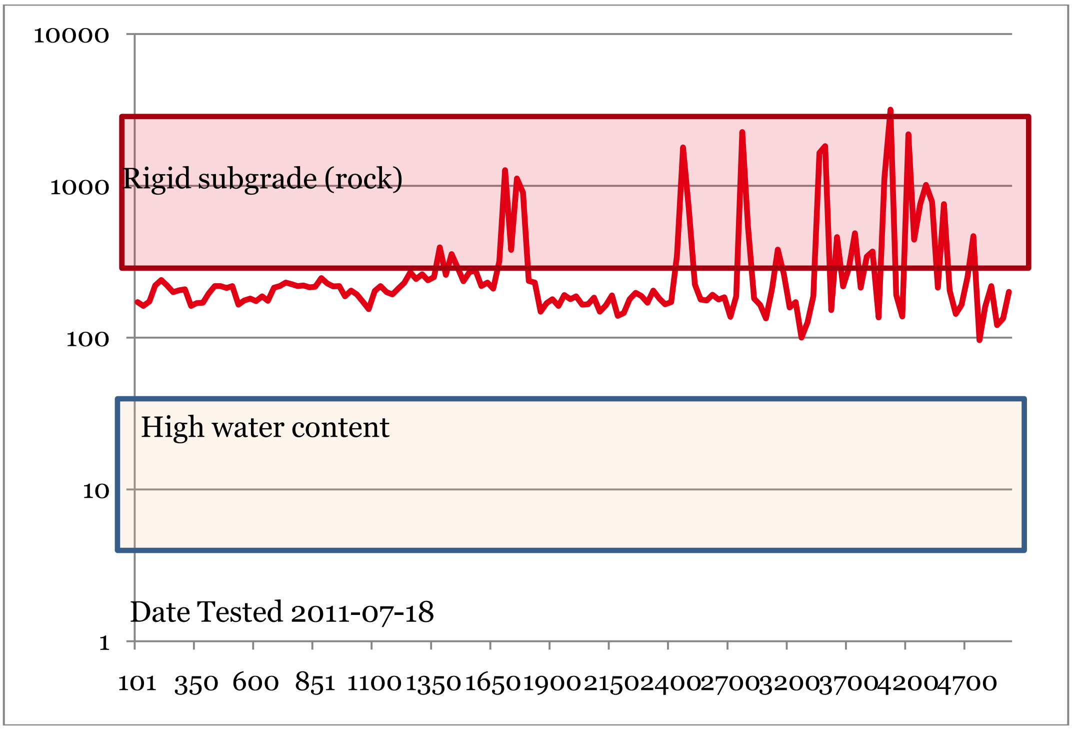

Figure 4: Subgrade modulus as tested on the existing road.

Time histories were sampled for all drops. They provide important information on the dynamic properties of the pavement. Figure 5 shows load deflection graphs for three sensors at 0, 30, and 150 cm offsets. If water is present the outer sensor curve would have been pushed to a negative deflection, i.e. heaving slightly, see Figure 6. The latter example is from the aforementioned project in Southern Sweden, 2006.

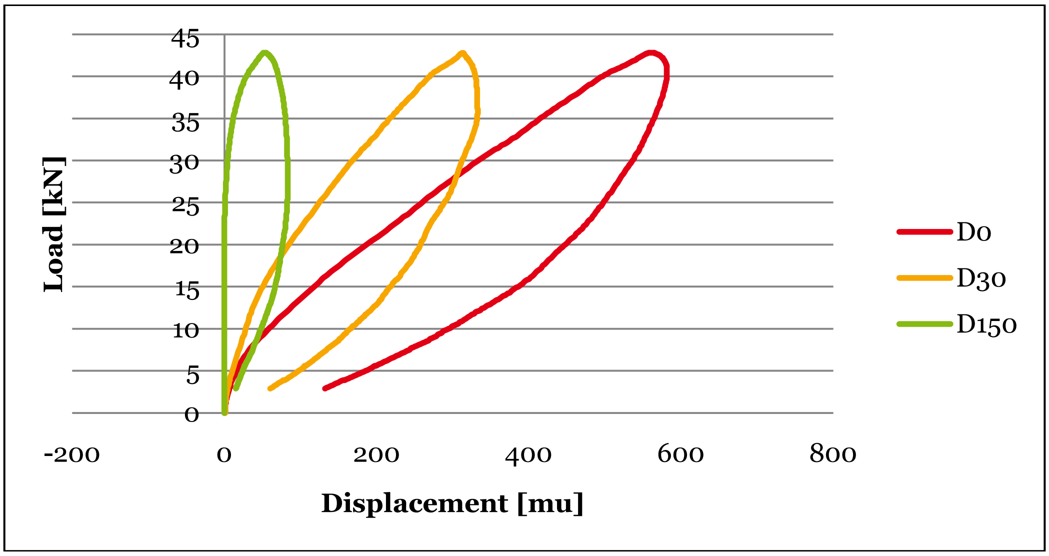

Figure 5: Load-Deflection plot revealed a normal behavior with no water present

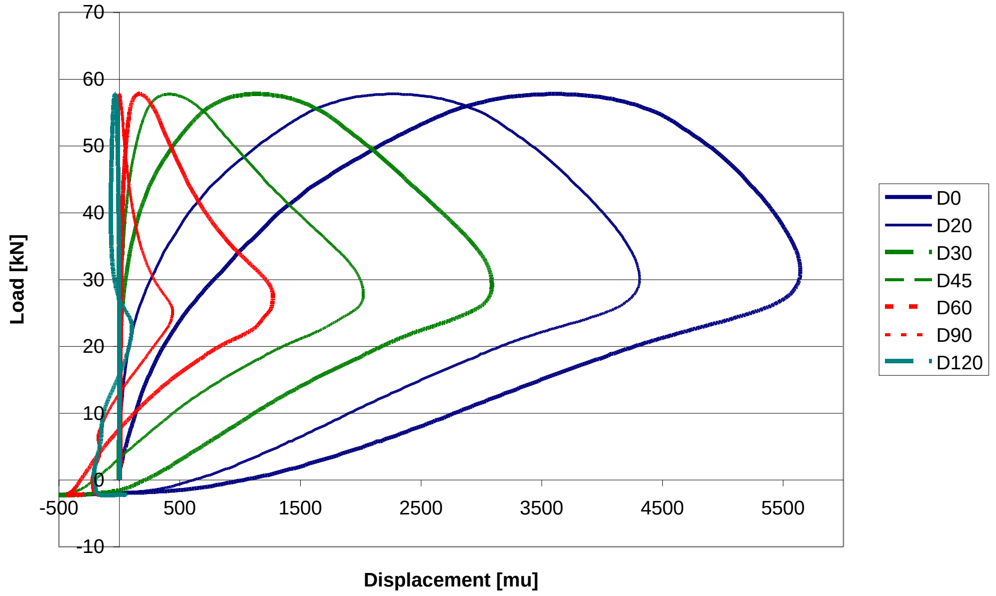

Figure 6: Time histories where outer sensors are being pushed by moving water

A prepared subgrade surface was finished by December 2011. An FWD was brought to the site, but when it arrived it was snowing and the surface was hard to access. Nevertheless, several data points were collected. Most of the sensors readings were rather bad though and many of the test stations had to be discarded. The remaining ones were backcalculated and the root mean square sensor error was rather high as was to be expected on the uneven surface. As the surface was very wet, the modulus appeared low. It was then decided to backcalculate two layers, a surface layer of 50 mm and the remaining subgrade separately. The latter would be assumed to be very close to the conditions after the road had been built. The upper 50 mm were just discarded as described from experience from the Minnesota Road Research Project, where all surfaces were measured during construction, (VanDeusen et al 1994). The average root mean square (RMS) for the backcalculated drops 8 to 10 was less than 12%. It is considerably higher than for tests on bound layers, but reasonable considering the rough surface texture. By excluding faulty sensor readings manually the error can be lessened further. For accepting basins to be included in the contract, a cut was made for those exceeding 30 % RMS. This is provided that at least 21samples are made on each homogenous section. As can be seen in Table 1, excluding basins over 15% RMS did not affect the statistics much. The subgrade values as such were considered acceptable, but there were practical issues to deal with during testing. The towing vehicle got stuck several times on the muddy surfaces. Heavy equipment had to assist it, which was not desirable on the prepared surface.

All tests were done with the 450 mm diameter load plate as to accommodate the spread of the load. The future interface would be about 600 mm down from the surface.

By contract regulations the PLT tests are normally conducted on the subgrade and unbound layer surfaces. The unbound base layer thickness is usually only 80 mm as to provide an even surface for the bound base coarse layer. When active design is used, the unbound base course thickness will vary as the bound base coarse thickness varies. Thus, it was suggested by the contractor to test on the subbase surface rather than the unbound base. This practice was accepted by the regional transport administration.

Table 1. Subgrade Modulus Backcalculated from FWD Subgrade Testing

	All basins	Above 15% RMS excluded
Number [n]	271	215
Mean [MPa]	168	163
Std. Variation	60	55
5-percentile	102	101
95-percentile	268	264

Given the length of the project it could not be tested in its entity at the same time, but a first visit occurred in early April 2012 and a second one in October 2012. The latter could not be included as the analyses were not ready by the time of the submittal of the present paper. However, several hundred drops were done on the new alignment, see Figure 7. In addition about half the length was covered for the sections to be widened.

Figure 7. The subbase offered a fair surface for FWD testing in April 2012.

Primarily the testing took place in the future wheel track in the near side lane, but some other tests were done near the edge and according to the PLT testing scheme. The latter tests were not required by the Transport Administration, but were done as a check procedure anyway for the students' evaluation. These tests were also done with the 450 mm diameter load plate. Seven sensors were used at distances shown in Table 2.

These tests could now double up as a modulus control for the subbase layer and in addition serve as design parameters for the asphalt bound layer thickness. Considering stress levels the 20 kN maximum load is closest to the actual traffic load with overburden as built. Thus drop number eight was chosen for this purpose. The last drop in each load level is usually producing the most elastic response. The requirements from the Transport Administration stipulated a minimum modulus of 150 MPa for the subbase layer. An example of one of the surfaces is shown in Table 3 below. The criterion was fulfilled for almost all sections tested. As the subgrade support is indeed good, the compaction of the subbase was easily executed.

The needed asphalt thickness is also listed and as one can see, four out of eight sections need less than 90 mm. This section across an old riverbed was originally assumed to need the three layer (135 mm) design. It is also a proof that a higher degree of compaction of the unbound material could pay off quite considerably.

Table 2: FWD configuration and set-up at the unbound layer measurements.

	1	2	3	4	5	6	7	8	9	10
Load Sequence [kN]	20	20	40	50	20	40	50	20	40	50
Sensor Spacing [mm]	0	300	450	600	900	1200	1500			

As it turned out from the subbase testing over 80% of the basins tested would fulfill the two strain criteria with only two layers (90mm) of asphalt concrete. This is better than expected from the initial test on the existing pavement. From a practical viewpoint this may not be quite achievable as some single points in between the 130 mm design points would not be considered. However, the unbound compaction could perhaps be improved, so that other stretches with a three layer design could be reduced to a 90mm design, e.g. the eastbound sections in Table 3.

Table 3: Example of Backcalculated Moduli

Distance	Direction	Subbase Modulus [MPa]	Subgrade Modulus [MPa]	Asphalt Concrete Need [mm]
800	E	280	110	113
850	E	268	103	116
900	E	330	98	103
950	E	522	126	77
950	W	305	124	103
900	W	313	121	81
850	W	442	113	77
800	W	313	119	86

4 FINDINGS

The mechanistic empirical design is indeed suitable for employing active design. The conventional test methods such as the PLT test may not be suitable for this purpose as the load is different from the traffic load. The standard 40 or 50 kN FWD load is closer to the traffic load, but by testing a several load levels and by storing time histories it is possible to recalculate the future as built conditions.

For some areas the FWD may not always be suitable as the access may be limited to subgrade surfaces. However, most subbase areas are easily accessible and they provide a better surface to test on. Backcalculation will also provide the subgrade and subbase properties at the same time.

The FWD test is much faster than the PLT and the total costs for testing may not be higher for the former. Besides a bound layer thickness design can be readily made.

Contracting with functional parameters, like roughness and rutting rate are suitable for this method.

The on site construction staff felt very motivated to provide as good unbound layers as possible in order to increase the area with two asphalt bound layers.

The road administration and contractor both have incentives to create more sustainable roads.

5 CONCLUSION

By testing moduli in situ on unbound surfaces, active design could be used to derive appropriate asphalt layer thickness. The design should meet traditional bottom of bound layer and top of subgrade criteria. In the present case about 26 % of the asphalt concrete was saved when compared to the standard mechanistic-empirical design procedure. Both methods use the exact same strain criteria, but the latter method is based on reliability for the entire project.

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