(DRAFT) Report from Mn/DOT IC-LWD workshop, held 14/11/2007, prepared by Dr P Fleming for Mn/DOT/John Siekmeier.

1. Review of project visit

- Detroit Lakes, 13-11-07, compaction control using the LWD, for a local well-graded sandy material.
- Target value of 40 MPa seems appropriate. Using the Zorn device is perhaps equivalent (assuming the stiffness is equivalent to a 300-mm diameter plate) to UK guide value of 65 MPa measured with a FWD/Prima for the top of sub-base (normal correlation factor of about 0.6). This value was the original target value for the old conventional 'standard' road foundation in the UK, but now termed a class 2 unbound granular foundation with a target of 80 MPa for good quality crushed rock.
- The Zorn seemed to be working well, easy to handle and notably the 200-mm diameter load plate was favoured.

2. Review of Workshop Day, by Dr Fleming

2a. The feedback from the morning group session, regarding experiences with the LWD used for site control of materials/methods, was of great interest to Dr Fleming and the European user community .

- The LWD is a rapid evaluation tool, easy and versatile, numbers are useful for material compaction compliance – though better on granular than fine grained cohesive.
- The Zorn is preferred over the Prima (agree with John that general term should be used in lieu of "Prima" for LWDs with load cells-happy to use LWD, and it is useful to include load cell, but of course LWDs include all varieties of what I would also term portable dynamic plate tests, and you may want to include in my report the fact that the LWD with a load cell finding greatest uptake in the UK and it seems most of Europe is that distributed by Carlbro and the proprietary name is the 'Prima' – this could perhaps be a useful footnote to the report) for ease of use by the highway inspectors.
- Much of the experience was positive, however, there was debate over the appropriate excavation depth to ensure that the material under the test was fully compacted. This depth seemed to vary depending on material type (later reinforced by Dr White's presentation).
- Dr Fleming's comments on the outcomes of the discussion groups are given in Section 3.

2b. Presentation by Dr Fleming
Dr. Fleming summarized some of the key aspects of changes in UK practice with regard to LWDs, and the latest advice from Europe pertaining to testing protocols. The following synthesis this presentation:

- There is a *lack* of uptake of German Zorn devices in many countries, wherein the 'Prima' type device, with both load and deflection measurement, was favoured.
- In general, the principle factors that can affect LWD measurements are: the erroneous assumption that layered materials under the test conform to an 'elastic half space' for simple analysis of insitu stiffness; the erroneous assumption that the deflection under load is elastic- and showed examples of deflection signal 'quality', including where further compaction was occurring; the significant effects of plate size and applied stress on the measured stiffness, especially of layered foundations; the significant effect of different constructions on the correlation between devices – using the FWD as the 'gold' standard

(or in some cases the static plate elastic stiffness); and the site material and position variability on a typical test length with different LWD devices.

- The size of variation accorded with that presented in Dr White's presentation, which is encouraging for standardization.
- The UK deals with variability by utilizing an 'averaging' and 'minimum' target stiffness value philosophy, such that target values allow for the expected site variations in absolute values.
- The outcomes of two recent (2007) UK and European discussion forums aimed at agreeing on a robust protocol for implementing LWDs as part of the UK performance-based specifications for road foundations.
- The use of the measured values is the main difference between the Mn/DOT and UK approach. In the UK, the stiffness data are not directly used to control compaction, but are used to show materials have been adequately worked and placed to provide a designated stiffness support to the layers above for their construction (and to protect the subgrade beneath), and also providing some assurance that long-term the foundation is expected to provide a suitable stiffness reaction to traffic loading (i.e. design confidence).
- The Zorn LWD was not readily taken up in the UK, primarily because it was considered to have too limited of a measuring range, and also because it repeatedly under-read average stiffness achieved when compared with the other LWDs or the full-scale FWD, by a factor of between 1.5 and 3. The UK's experience with accelerometers was also a factor, and it is generally accepted in the UK that the Zorn is not as 'accurate' as the Prima. However, the UK's experience was also similar to that expressed at the workshop, regarding user friendliness, the Zorn being more robust and easier to man-handle than the Prima type LWDs.

2c. Intelligent Compaction (IC)
The feedback session on the experiences with IC was very interesting, and the details are provided in the separate formal Mn/DOT workshop report.

Intelligent Compaction is not specified in the UK, where the traditional method specification is and has been used for some time on many schemes, or simple end-product specifications, with testing for adequate density by nuclear methods or sand-cone (less common now). The UK policy on Nuclear density tests is, in the author's opinion, still that their widespread use is acceptable.

The use of Intelligent Compaction, or research with regard to its use in the UK, is currently under review to be fed back to the Mn/DOT team where appropriate.

3. Comments on the Workshop Report (LWD use only)
This section has been produced post circulation of the official Mn/DOT report (Embacher, 2007) on 10th December 2007. Section 1.0, therein, comprises a series of lists of the group feedback statements and outcomes regarding the use of LWDs. The comments below are intended to supplement these with experience gained in the UK by Dr Fleming and from his general knowledge of the subject.

1.1 Positive characteristics: These all seem very appropriate and sensible. The added advantage of the LWD over the DCP is also that the LWD is non-destructive/non-intrusive, and that the number it measures is better related to analytical design techniques.

1.2 Troubles/concerns:

Item 2. The removal of crust seems subjective, albeit that the crust is transient. In the UK. testing is always done at the surface of any layer, and just prior to construction of the next layer – but is performance related not directly aimed at compaction control.

Item 6. In the UK there has been no move to alter the weight of the device, 10kg is considered a reasonable mass to lift. A trolley with soft pneumatic tires is often used by technicians to move the device around (refers to item 15 also).

Item 8: What is good enough? This was researched in the UK over many years, and with regard to performance of a layer was approached in three ways: using experience of appropriate values found from sites with traditional materials used in traditional ways – i.e. expected adequate performance; backcalculation and adjustment of stiffness values derived from FWD testing at in-service roads; literature and analytical design guidance where likely stiffness values were indicated for the same or similar materials (e.g. UK research and also European practice in Germany, France, Holland was drawn upon – where static plate testing for compliance had been heavily utilized for design on subgrades and compliance testing of road foundation layers after construction).

Item 12: Issues of consistent data when testing sands may be due to plastic deformation affecting the results, if the near surface layer is not compacted so well (steel vibrating drum effect), also possibly refers 1.3 item 4.

1.3 Quantitative Results:

Items 5, 7 and 8, are related with regard to modulus increasing where there may be dissipation of excess pore pressures and some ‘relaxation’ causing improved particle contact or ‘apparent’ confinement. This has also been observed in UK soils/aggregates in laboratory testing and in the field, and in some cases testing is recommended after 24 hours to show the benefits of this behaviour. (f).

Item 6 regarding compaction and target modulus values is also a difficult one to address. UK experience suggests that while density can remain reasonably constant, the stiffness can vary due to its sensitivity to stress state (porewater pressures, confinement etc), and so the setting of target values to confirm adequate compaction is relatively complex, and also depends on the test as well as the material state. In general, from UK field trials the stiffness tends to peak around the optimum number of passes of a vibrating roller on granular soils (refer to Fleming/Frost papers for more detail).

1.4 Moisture Effects: All seem sensible and appropriate.

1.5 QC Contractor Responsibility: Item 1 is always an issue, as discussed the MCV apparatus is used in UK and elsewhere for earthwork material and m/c acceptance.

1.6 Testing Procedures: These all seem appropriate, though again in UK we test on the top of compacted layers, and also just before the next layer is to be placed to ensure adequate performance at the time it is needed most. Item 9: Frequency/spacing seems rather wide, more likely to identify soft spots if testing at a closer spacing.

1.7 Changes for next Year: Seem appropriate.

Other general comments on the report:

1.6 Items against my presentation are okay, but to clarify – item 5, standard plate contact stress in UK is 100kPa, from 300-mmPlate, though there are moves to permit higher contact stress on the stiffer materials (Class 3&4).

1.7. Dr White's report: Agree with his points regarding LWD modulus sensitivity (item 11) and testing protocol (item 12), and CoV values (item 13).

4. Comments/recommendations on future direction of Mn/DOT LWD-IC research

Compaction control
In brief, my general opinion of what you are trying to achieve at Mn/DOT and the processes in place all seem excellent and should yield good workable specifications for implementation, as is already occurring. Some of the more fundamental questions that arose regarding LWD testing and analysis should ideally be resolved through Dr White's research program. It might be appropriate to revisit the program aims and objectives, and direct future work to help further focus on these, particularly with regard to cohesive soils, time dependent stiffness effects and target value setting. We did a similar process in the UK but as we got closer to implementation of our new specification philosophy we lacked the resources to carry out further research into some of these aspects (to my satisfaction) and which were perhaps not flagged up as clearly as in your workshop. I do expect these to be raised in the UK however as the new procedures are more widely used.

In the UK, the use of lightweight deflectometers for performance-based construction quality assurance and design validation is still lacking some aspects of lengthy experience and robust testing protocols or detailed standards for industry, though the UK performance based designs and standards are currently under review by the UK Highways Agency (feedback from users included over-complexity). However, against this backdrop, the UK philosophy for the road network has (in recent years) moved to upgrading and widening, with few strategic new routes under consideration or construction. Thus, the role of the LWDs will perhaps be more focussed on evaluation of in-service road foundations during investigation and reconstruction, or QA of extra lanes during construction.

Recent European activity has also produced a relatively new LWD in Hungary, aimed directly at measurements for compaction control, with a device very much akin to the Zorn in appearance but with a 165-mm diameter plate – aimed to provide a dynamic energy similar to the compactive energy of a traditional proctor compaction test. Information was passed to John Siekmeier, and any further developments will be passed on.

4. Further support offered to Mn/DOT
As new guidance is published and experience discussed in the UK, I will endeavour to update Mn/DOT through the appropriate channels (John Siekmeier for the coming period). In addition, I am also happy to provide any useful input into ongoing review/feedback of any Mn/DOT practice, experience, research findings, and specifications in relation to LWDs and road foundations. Much of the UK research and development in this field, including LWDs

and related testing and specifications, has been published in Transportation Research Records, and thus is available through the TRB in Washington.

5. References

Embacher, R, 2007, 'Intelligent Compaction and Lightweight Deflectometer technology Transfer Workshop', Final Report from the one day workshop at Mn/DOT Baxter Headquarters, 14 November, Mn/DOT.