Client Report :

The use of Control planks to determine the within and between variability of UK based strength grading machines: Part 1 Characterisation of the Control planks.

Client report number 80322

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Executive Summary

This project was set up to address the concerns of the UK timber grading Industry with regard to the degree of possible within and between machine variability. This was a collaborative project between the Forestry Commission, the United Kingdom Forest products Association (UKFPA), TimberSolve and BRE. The project consists of 2 parts; the first part, to which this report relates, is on the characterisation of the control planks that are to be used to determine the within and between machine variability. The second, which is the collection of data to determine the current amount of variability within and between strength grading machines is subject of a further report by TimberSolve.

The present concern arose due the intention to implement, as part of a new standard (TC124 -1.1, which incorporates EN519) the use of control planks for daily, routine control of strength grading machines. It was suspected that due to the believed variability of the current grading machines being used within the UK, that they would regularly fall outside the limits that may be imposed by the standard. If their suspicions were correct this would have major cost implications for the UK industry. There was an EU project underway which was focused on the research needed to design and produce control planks and draft the clauses relating to their use for the standard but no research had been carried out to determine the natural variability of the machines.

This report deals only with part 1 covering the characterisation of the planks and determining the amount of innate variability that exists within the planks. It would be impossible to determine the amount of within and between machine variability without first determining the behaviour of the planks.

Three plank designs were used and this report outlines the findings as to the amount of within plank variability and how this is influenced by the machine speed (3 machine speeds were investigated). It also covers the potential for plank degradation, caused by wear, or fatigue to affect the apparent machine performance and general non-specific plank behaviour.

It is not the intention to draw direct comparison between plank design but to learn general lessons that may aid future control plank designers. Also to highlight points that may be relevant to those having to interpret the data from grading machine that are regularly checked by the use of control planks.

The findings of this report show that:

- 2 of the 3 planks investigated, the Saab and the TS, showed sufficiently low within plank variability as to be acceptable for the second part of this project, to evaluate within and between machine variability.
- the LVL plank showed too great a within plank variability to be acceptable for determining within and between machine variability.

- The TS plank should be restricted to machine speeds of upto105/min for the evaluation of within and between machine variation.
- Although some differences were noted when the planks were tested at different machine speeds, this should not be regarded as deterioration in the plank. Post testing static calibrations of the planks indicated that no deterioration had taken place.

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Introduction

The control and calibration of strength grading machines in the United Kingdom has been and still is under the control of the third party certification bodies. This usually takes the form of checks made periodically throughout the course of a year. Between these checks the machines are assumed to perform adequately, unless a significant problem arises that requires the machines to be re-calibrated.

A growing number of anecdotal reports indicate that some producers of strength graded timber have discovered that machines supposedly set up in a similar manner and set to grade the same strength classes of timber exhibit a variation within their performance greater than that expected by simple manufacturing differences. This in itself was troubling and warranted investigation. However, the proposed introduction of control / calibration planks for the daily checking of machines into the draft head standard for structural timber raised the concerns of those producing machine strength graded timber and machine manufactures.

The proposal to introduce the use of control planks was included in the draft head standard (EU document working draft TC124-1.1) [1]. This standard is the head standard for all structural timber standards and would include the current EN519 machine-grading standard. An EU funded project had been carried out to investigate the potential of developing calibration planks for the dynamic control and calibration of bending type machines. This (EU project 3454/0/171/91/9-BCR-UK(30))[2] highlighted the difficulties of designing planks that had the required technical performance and durability. However, draft clauses for the use of calibration planks with strength grading machines were drafted. Events overtook the introduction of these clauses into the machine grading standard (EN519) in the form of a review and revision of the current EU structural timber standards and the introduction of an increasing number of new technologies that had been or could be applied to strength grading of timber. These new technologies required more information to be gathered and the existing draft clauses for bending type machine re-addressed in line with the new technologies. Consequently the CONGRAD[3] project was conceived to carry out the research into plank designs and materials and concurrently draft clauses for inclusion in the new head standard.

In response to the proposal to introduce daily checks on the grading machines by control / calibration planks, the UK producers of machine graded timber expressed concern that this may have a significant impact on their production. In particular their concern centred on the anecdotal evidence that the machines in use potentially had within and between machine variability greater than that required for compliance with the control/calibration planks. As a consequence they were concerned that machines may spend long periods or regular periods out of operation requiring expensive calibrations to be carried out.

This present project to address these concerns was conceived to study the potentially for within and between machine variation by using a number of control plank designs to determine the performance of production based grading machines for a range of types commonly used in UK sawmills. The project was jointly funded by the Forestry Commission and the United Kingdom Forest Products Association (UKFPA).

Description of the project

The project was divided into to two clearly defined parts; Part 1 was the characterisation of the innate variability of each of the planks used in the project. This work was carried out at the BRE. Part 2 was the evaluation of a range of grading machines commonly used in the production of strength graded timber to determine the within and between machine variability. Part 2 is to be carried out by TimberSolve.

This report specifically relates to Part 1 of the project.

Part 1: Characterisation of the control planks to determine the innate variability that exists within each plank and determine the response to machine speed.

The control planks.

Three planks were used but only one was specifically made for use in the study. The two remaining planks had their origins for other specific purposes but were used in the project to widen the scope and because each had characteristics that were desirable for the study. The planks were designated the following notation by which they will be referred to in the following text. Saab plank, TS plank and LVL plank.

All planks were used as control planks as opposed to calibration planks. Control planks are used to routinely determine the performance of a machine by measuring the precision of the machine's response to the plank and comparing this to previous uses. A calibration plank is a diagnostic tool used for correcting or optimising the performance of a machine, and is therefore a more difficult tool to design, manufacture and maintain.

Saab plank

The Saab plank consists of an aluminium honeycomb covered in plastic sidings and all covered in a polymeric coating. The polymeric coating acts as a bearing and mechanical handling surface with low light reflectivity. The plank contained a section of reduced stiffness, original to be 25% lower in stiffness than the remaining plank body. The area of reduced stiffness was placed centrally in the plank and covered a linear length of 1200mm. The total plank length was 5000mm, the thickness was 37mm and the depth was 155mm. The total weight was 17.75kg.

This plank was the most promising plank from the first EU calibration plank project. It had been kept at BRE since the completion of the project in 1994. The plank has made an estimated 4000 passes through various grading machines, most often the Cook-Bolinder at BRE. Even though having made an estimated 4000 passes the plank still shows good repeatability and low variability.

TS plank

This is an aluminium and plywood composite plank originally designed to be used to resolve a particular problem with a particular type of machine. The main stiffness is imparted to the plank by aluminium bars to which a plywood covering is fixed, in a manner that reduces composite action between the plywood and the aluminium. The plywood acts as a bearing and mechanical handling surface. The plank contains two areas of reduced stiffness each covering a linear distance of 450mm. One in the leading portion and one placed centrally. The total length of the plank is 3055mm, the thickness is 35mm and the depth 73mm. The total weight is 11.2kg.

LVL plank

Both the Saab and the TS planks are relatively expensive to manufacture and so the LVL plank was an attempt to produce a reduced cost or more economic plank. This work was an opportunity to determine the potential of the plank and compare the performance against the more expensive types of control plank.

The body was a single piece of LVL with an area of reduced stiffness placed centrally. The plank had no additional features; the action of mechanical handling was borne by the surface of the LVL. The plank contained a single centrally placed area of reduced stiffness 600mm in linear length. The total plank length was 4203mm, the thickness was 44mm and the depth was 220mm. The total weight was 26.5kg.

Two LVL planks were produced, one to characterise the behaviour of the plank and one for machine testing. Both planks were made to the same TimberSolve design in the BRE machines shops.

Testing

Before any of the planks were passed through the grading machine a series of static calibrations was carried out to determine the stiffness of the plank at positions along the plank length equivalent to those used by the grading machine to determine stiffness. These calibrations were repeated when the planks had completed the 300 passes.

All three types of plank were tested using the BRE Cook-Bolinder machine. The aim of the testing was to determine the innate character of each plank with regard to within plank variation and how this was affected by machine speed. Three machine speeds were selected and these were 60m/min. used as the standard BRE reference speed, 105m/min. as the maximum speed that computermatics are permitted to run and 150m/min. the maximum speed a Cook-Bolinder is permitted to run. This characterisation data would be used in Part 2 of the study to determine whether variations between the performance of a number of machines was due primarily to differences relating to the machine or to the innate character of the plank. It would also give a measure of the individual machine precision and within variability.

As importantly it would also give an indication as to when the planks could be expected to deteriorate in performance due to wear or fatigue and thereby have an influence on the machines apparent performance.

For each of the three speeds the planks were passed a total of 100 times and the reaction loads noted at 100mm intervals. The TS plank had the bolts holding the plywood to the aluminium inserts checked every 25 passes and they were adjusted to finger tight when necessary. It should be noted that while this method of repetitive testing is common to determine the performance of a plank, it is divorced form what would be expected to happen in practice. Repeatedly passing the same plank through a machine increases wear at a rate greater than a similar number of passes with one or two passes made a day. Most planks show an ability to recover their initial performance after a period of rest and a deterioration in the performance of any plank should take this into account of before accepting that a permanent deterioration has taken place.

Testing at each speed was continuous within the time frame of the working day. That is to say once testing of a plank at a particular speed had commenced, the longest duration of inactivity was over night. Between tests at differing speeds a minimum of 24 hours was allowed to rest the planks.

ANALYSIS

Analysis of the data was carried out to determine:

- any significant differences between the first and the hundredth pass for a given speed?
- the amount of variability that could be expected within the plank for a given speed.
- the amount of variability that could be expected within a plank due to varying the machine speed.
- any significant differences between the results of various machine speeds.
- any discernible deterioration in the performance of the plank that could not be accounted for by machine speed or regained after a period of rest (recovery).

Findings

Results of the tests are given in the annex to this report.

Saab Plank

1. The static calibration matched well with the dynamic results from the grading machine for passes made at 60m/min but tended to drift from these values as the machine speed increased. The post-testing calibration showed no significant differences form the pre-testing calibration as determined by statistical methods. The beginning and end points of the area of reduced stiffness was clearly defined.

2. No significant difference was determined using f and t-test statistics between; speed 60m/min pass 1 and pass 100. Speed 60m/min pass 1 and speed 105m/min pass 1. Speed 60m/imn pass 1 and speed105m/min pass100. Speed 60m/min pass 1 and speed 150m/min pass1.

3. A significant difference was found between; speed 60m/min pass1 and speed 150m/min pass100.

4. The co-efficient of variation(COV), a measure of within plank variation, for the whole plank, remained constant over the range of tests with the exception of the highest speed. This indicates that while there was a slight but significant difference between passes1 speed 60m/min. and pass100 speed150m/min., the amount of within plank variation was constant up to pass 100 machine speed105m/min. (see Table 1 in the annex).

5. The area of reduced stiffness was clearly defined at all speeds and for all passes and the values displayed remarkable consistency and precision.

6. The coefficient of variation for the individual grader points showed a slight rise as the machine speed increased. However, this was low when the magnitude of the applied bending force was considered, (see Table 2 in the annex). This can be taken as an indication of the natural noise within the plank generated by the machine speed.

7. The difference between the minimum and maximum value for any grader point over the100 passes expressed as a percentage of the mean value for the same point was 5% for 60M/min, 7% for 105M/min and 8% for 150M/min.

8. There was moderate tail-end vibration as the plank passed through the grading machine.

TS Plank

1. The static calibration matched well with the dynamic results from the grading machine for passes made at 60M/min but tended to drift from these values as the machine speed increased. The post testing calibration showed no significant

difference form the pre testing calibration as determined by f and t-test statistics. The start of the second area of reduced stiffness is defined at the beginning but tails off with no clearly defined end. The grading machine has only partly captured the first area of reduced stiffness due to its position within the plank.

2. A significant difference was found to exist between; speed 60m/min pass1 and speed 105m/min pass1. Speed 60m/min pass1 and speed 105m/min pass100. Speed 60M/min pass1 and speed 150m/min pass1. Speed 60m/min pass1 and speed 150m/min pass 100.

3. Whilst no significant difference was found between; speed 60M/min pass1 and pass100.

4. The coefficient of variation for the plank as a whole tended to increase as the machine speed increased. However, the COV for the tests carried out at; 60M/min were the lowest of the three planks, 105M/min they were comparable with the Saab plank. 150M/min.exceeded the values of the Saab plank (see Table 1in the annex).

5. The COV for the individual grader points tended to increase with increasing machine speed and number of passes (see Table 3 in the annex).

6. The differences between the minimum and maximum value for any grader point over 100 passes, expressed as a percentage of the mean value for the same point was 15% for 60m/min, 28% for105m/min and 45% for 150m/min.

7. The area of reduced stiffness was discernible for machine speed of 60M/min but definition was reduced as the machine speed increased.

8. There was minimal tail-end vibration as the plank entered the machine.

9. The plywood-bearing surface showed signs of wear and handling damage after the 300 passes. However, this wear was insufficient to affect the performance of the plank.

LVL plank

1. The static calibration matched reasonably well with the dynamic results obtained from the grading for 60m/min but tended to drift as the machine speeds increased. There was no discernible difference between the pre-test calibration and the post-test calibration. The presence of the area of reduced stiffness was indicated but poorly defined with no clear beginning or end point.

2. There was no significant difference detectable for all passes and all speeds for whole plank variability.

3. The COV's for the whole plank per pass were high, far in excess of either the Saab or the TS plank, but over the range of speeds remained more or less consistent and with no discernible pattern to increase with machine speed (see Table 1 in the annex).

4. The COV for individual grader points was high but remained constant over the range of the tests (see Table 4 in the annex).

5. The difference between the minimum and maximum value for any grader point over 100 passes expressed as a percentage of the mean value for the same point was: 24% for 60m/min, 39% for 105m/min and 32% for 150m/min.

6. The COV was so high that the area of reduced stiffness was difficult to define for all speeds.

7. There was a tendency for a high degree of tail-end vibration starting at high amplitude / low frequency but as the length of the plank extending from the in-feed reduced, the mode changed to low amplitude / high frequency. This increased with machine speed.

8. After the 300 passes the surface of the plank was beginning to break up by splintering and de-lamination. This was only the surface appearance and it did not affect the performance of the plank.

General comments.

All planks showed a reaction in the first few readings to striking the defection plate as the defection is forced on the plank and the plank is gripped by the out feed rollers. Each plank reacted differently and by a differing amount. This is unique to the plank / machine combination and should not be viewed as a source of within or between variation for the purposes of the project.

The readings either side of and including the area of reduced stiffness are the most important for repeatability testing and these readings should show the least natural variability or innate “noise”.

Conclusion and recommendations

- Both the SAAB and the TS planks showed a degree of variability that is just about acceptable for determining the within and between variability of strength grading machines. They are at the upper limit of what may be considered desirable. It may be wise to restrict the TS plank to machine speeds of 105m/min and below. With the measured natural variability or innate noise it should be possible to determine the degree of machine variability that exists.
- The LVL plank should not be used for determining the within and between variability of strength grading machines as the natural variability or innate noise within the plank is too great to obtain meaningful results.
- The TS plank should have the bolts fixing the plywood sides to the aluminium checked regularly when in use for the second part of this project. Rather than checking at every 25 passes as in this study the recommendation is that they be checked every 10 passes.
- Though a difference existed between the start of a series of tests and the completion, significant in some cases, this should not necessarily be taken as deterioration within the plank. All the planks showed some degree of recovery between tests, and the static calibrations before testing and after 300 passes indicated that there was no significant difference after a period of rest. It was more the nature of the testing regime than the deterioration that was being detected.
- All the planks showed some degree of being machine speed specific and this should noted for the second part on the evaluation. An accurate measure of machine speed must be determined to make the data acquired meaningful.

Part 1: Characterisation of the Control planks.

References

1). CEN (2000): Timber structures – Strength graded structural timber with rectangular cross-section: CEN/TC124N 337 to 339, Draft EN TC124-1.1 parts 1 to 3, February 2000.

2). Fewell A F 1994; EU project 3454/0/17/91/9-BCR-UK(30)), The development of calibration planks for timber stress grading machines. BRE 1994. CR95/94.

3). Bosrom L 2000; CONGRAD: Control of timber strength grading machines, Draft final report, SP2000:

Annex

This annex contains:

Table 1). Basic statistical data relating to the mean of the grader readings for the whole plank, with relation to the first and last pace at each machine speed.

Table 2). Co-efficient of variation form the mean of the individual passes at each grader point over a range of points to include the area of reduced stiffness for each of the 3 machine speeds; SAAB plank.

Table 3). Co-efficient of variation form the mean of the individual passes at each grader point over a range of points to include the areas of reduced stiffness for each of the 3 machine speeds; TS plank.

Table 4). Co-efficient of variation form the mean of the individual passes at each grader point over a range of points to include the area of reduced stiffness for each of the 3 machine speeds; LVL plank.

Figure 1). Saab plank - repeatability.

Figure 2). Saab plank: Comparison of the mean of 2static calibrations with pass 1 at machine speed 60m/min.

Figure 3). TS plank - repeatability.

Figure 4). TS plank: Comparison of the mean of 2 static calibrations with pass 1 at speed 60m/mm.

Figure 5). LVL plank – repeatability.

Figure 6). LVL plank: Comparison of the mean of 2 static calibrations with pass 1 at speed 60m/mm.

Table1. Basic statistical data relating to the mean of the grader readings for the whole plank, with relation to the first and last pass at each machine speed.

Plank type	Pass number / machine speed m/min.					
	1/60	100/60	1/105	100/105	1/150	100/150
Saab Standard deviation	0.3560	0.3850	0.3556	0.3601	0.3503	0.4523
Variance	0.1268	0.1482	0.1265	0.1297	0.1237	0.2045
Coefficient of variation	0.0920	0.0974	0.0885	0.0923	0.0893	0.1108
TS Standard Deviation	0.0705	0.0756	0.0912	0.0938	0.1072	0.1565
Variance	0.0050	0.0057	0.0083	0.0088	0.0115	0.0245
Coefficient of variation	0.0762	0.0828	0.1027	0.10590	0.1149	0.1494
LVL Standard deviation	1.0562	0.9037	0.9689	1.0670	0.9403	1.1418
Variance	1.1155	0.8166	0.9388	1.1384	0.8842	1.3038
Coefficient of variation	0.1486	0.1281	0.1358	1.1708	0.1285	0.1583

Table 2. Co-efficient of variation from the mean of the individual passes at each grader point over a range of points to include the area of reduced stiffness for each of the 3 machine speeds; SAAB plank.

SAAB plank	Machine speed 60m/min				Machine speed 105m/min				Machine speed 150m/min			
Grader Pos.	COV mean	Min. value KN	Max value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN
7	0.0103	4.08	4.25	0.17	0.0159	3.91	4.18	0.27	0.0200	3.89	4.29	0.4
8	0.0081	4.03	4.21	0.18	0.0137	3.92	4.26	0.34	0.0143	3.84	4.16	0.32
9	0.0080	3.98	4.14	0.16	0.0141	3.92	4.182	0.26	0.0138	3.84	4.16	0.32
10	0.0123	3.82	4.02	0.2	0.0179	3.78	4.123	0.343	0.0716	3.73	4.02	0.29
11	0.0188	3.39	3.84	0.45	0.0230	3.53	3.94	0.41	0.0213	3.49	3.87	0.38
12	0.0141	3.35	3.61	0.26	0.0146	3.43	3.69	0.26	0.0201	3.33	3.58	0.25
13	0.0082	3.3	3.45	0.15	0.0134	3.31	3.51	0.2	0.0159	3.25	3.44	0.19
14	0.0087	3.24	3.39	0.15	0.0121	3.26	3.52	0.26	0.0156	3.24	3.51	0.27
15	0.0099	3.22	3.39	0.17	0.0136	3.24	3.45	0.21	0.0158	3.21	3.46	0.25
16	0.0097	3.24	3.39	0.15	0.0143	3.25	3.44	0.19	0.0142	3.24	3.49	0.25
17	0.0071	3.28	3.4	0.12	0.0151	3.26	3.45	0.19	0.0116	3.27	3.48	0.21
18	0.0074	3.3	3.4	0.1	0.0154	3.29	3.46	0.17	0.0151	3.27	3.49	0.22
19	0.0086	3.31	3.4	0.09	0.0148	3.28	3.45	0.17	0.0157	3.23	3.47	0.24
20	0.0110	3.29	3.44	0.15	0.0188	3.3	3.52	0.22	0.0159	3.26	3.48	0.22
21	0.0104	3.33	3.54	0.21	0.0212	3.35	3.63	0.28	0.0186	3.43	3.76	0.33
22	0.0208	3.53	3.81	0.28	0.0143	3.59	3.81	0.22	0.0163	3.62	3.95	0.33
23	0.0143	3.8	4.02	0.28	0.0160	3.8	4.06	0.26	0.0134	3.77	4.02	0.25
24	0.0148	3.95	4.17	0.22	0.0165	3.93	4.18	0.25	0.0219	3.76	4.17	0.41
25	0.0086	4.05	4.29	0.24	0.0159	4.03	4.28	0.25	0.0169	4.08	4.41	0.33
26	0.0103	4.09	4.32	0.24	0.0166	4.07	4.35	0.28	0.0194	4.02	4.41	0.39

Table 3. Co-efficient of variation from the mean of the individual passes at each grader point over a range of points to include the areas of reduced stiffness for each of the 3 machine speeds; TS plank.

TS plank	Machine speed 60m/min				Machine speed 105m/min				Machine speed 150m/min			
Grader Pos.	COV mean	Min. value KN	Max Value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN
1	0.0326	0.81	0.94	0.13	0.0836	0.65	0.97	0.32	0.0824	0.59	0.86	0.27
2	0.0477	0.73	0.93	0.2	0.0734	0.65	0.93	0.28	0.0949	0.65	1.01	0.36
3	0.0335	0.74	0.87	0.13	0.0605	0.71	0.95	0.24	0.0775	0.55	0.93	0.38
4	0.0389	0.82	0.97	0.15	0.0662	0.71	1.09	0.38	0.0770	0.71	1.03	0.32
5	0.0282	0.86	1.01	0.15	0.0577	0.82	1.01	0.19	0.0857	0.74	1.160	0.42
6	0.0209	0.9	1	0.1	0.0366	0.87	1.04	0.17	0.0565	0.87	1.15	0.28
7	0.0978	0.9	1.08	0.18	0.1366	0.87	1.06	0.19	0.0893	0.83	1.32	0.49
8	0.0293	0.91	1.04	0.13	0.0638	0.84	1.09	0.25	0.1348	0.75	1.35	0.6
9	0.0198	0.85	0.96	0.11	0.0312	0.82	0.94	0.12	0.1034	0.73	1.2	0.47
10	0.0444	0.79	0.96	0.17	0.0581	0.72	1.04	0.32	0.0893	0.71	1.17	0.46
11	0.0307	0.76	0.89	0.13	0.0749	0.71	0.97	0.23	0.1329	0.71	1.28	0.57
12	0.230	0.79	0.86	0.07	0.0353	0.76	0.9	0.14	0.1075	0.65	1.14	0.49
13	0.0463	0.8	0.99	0.19	0.0678	0.72	1.03	0.31	0.1135	0.75	1.18	0.45
14	0.0369	0.81	0.96	0.15	0.0717	0.78	1.08	0.3	0.1628	0.69	1.37	0.68
15	0.0237	0.88	1.01	0.13	0.0507	0.85	1.09	0.24	0.1178	0.81	1.31	0.5
16	0.0349	0.89	1.06	0.17	0.554	0.87	1.16	0.29	0.0935	0.85	1.32	0.47
17	0.0320	0.92	1.04	0.12	0.0611	0.89	1.13	0.24	0.1285	0.81	1.34	0.53
18	0.0197	0.93	1.05	0.12	0.0312	0.93	1.05	0.12	0.0944	0.79	1.3	0.51
19	0.0295	0.95	1.11	0.16	0.0451	0.94	1.24	0.3	0.1009	0.89	1.34	0.45
20	0.0206	0.96	1.07	0.11	0.0462	0.93	1.14	0.21	0.0983	0.92	1.35	0.43
21	0.0247	0.96	1.06	0.1	0.0440	0.96	1.09	0.13	0.0841	0.94	1.28	0.34

Table 4. Co-efficient of variation from the mean of the individual passes at each grader point over a range of points to include the area of reduced stiffness for each of the 3 machine speeds; LVL plank.

LVL plank	Machine speed 60m/min				Machine speed 105m/min				Machine speed 150m/min			
Grader Pos.	COV mean	Min. value KN	Max value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN	COV mean	Min value KN	Max value KN	Diff. KN
7	0.0581	5.17	7.18	2.01	0.0802	4.95	7.52	2.57	0.0411	5.96	7.53	1.57
8	0.0595	5.59	7.42	1.83	0.0423	6.13	7.69	1.56	0.0732	5.1	7.94	2.84
9	0.0563	5.79	7.1	1.31	0.0603	4.57	7.53	2.96	0.0518	5.73	7.72	1.99
10	0.0529	5.87	7.36	1.49	0.0961	4.2	6.8	2.6	0.0389	6.65	8.34	1.69
11	0.0571	5.64	7.12	1.48	0.0996	4.56	7.14	2.58	0.0407	6.66	8.09	1.43
12	0.0557	5.58	7.26	1.68	0.0566	5.72	7.58	1.86	0.0488	5.91	7.6	1.69
13	0.0561	5.52	6.87	1.35	0.0860	4.09	6.95	2.86	0.0823	4.51	7.44	2.93
14	0.0664	5.23	6.89	1.66	0.1053	4.12	6.85	2.73	0.0777	4.44	7.37	2.93
15	0.0591	4.8	6.33	1.53	0.0765	4.86	6.95	2.09	0.0615	5.51	7.26	1.75
16	0.0583	4.78	6.1	1.32	0.1412	2.54	6.21	3.67	0.0973	4.49	7.43	2.94
17	0.0611	4.17	5.84	1.67	0.0910	3.82	6.46	2.64	0.1444	3.51	7.76	4.25
18	0.0604	4.52	5.89	1.37	0.1257	3.2	6.1	2.9	0.0898	4.44	7.18	2.74
19	0.0565	4.69	6.07	1.38	0.1061	3.68	6.51	2.83	0.1141	3.75	6.74	2.99
20	0.0627	4.78	6.35	1.57	0.0973	3.71	6.79	3.08	0.0754	4.74	7.49	2.75
21	0.0570	5.38	6.67	1.29	0.0735	4.7	6.99	2.29	0.0712	5.35	7.23	1.88
22	0.0615	5.51	7.09	1.58	0.0687	5.3	7.44	2.14	0.0536	5.58	7.54	1.96
23	0.0556	6.19	7.39	1.2	0.0487	5.83	7.54	1.71	0.0382	6.61	8.02	1.41
24	0.0543	6.35	7.69	1.34	0.0435	6	7.76	1.76	0.0360	6.84	8.3	1.46
24	0.0613	6.69	9.01	2.32	0.0424	6.67	8.24	1.57	0.0344	7.09	8.99	1.9
26	0.0550	6.78	8.28	1.5	0.0381	6.65	8.02	1.37	0.0252	7.03	8.28	1.25
27	0.0521	6.9	8.13	1.23	0.0387	6.66	8.6	1.94	0.0230	7.76	8.56	0.8

Part 1: Characterisation of the Control planks.