THE INFLUENCE OF DRILL-BIT ON THE MEASURED VIBRATION EXPOSURE OF HAMMER DRILLS

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Abstract

The OPERC HAVTEC database of hand-transmitted vibration exposure contains measurements for a wide range of hand held power tools (tested to ISO 5349). This paper examines measured vibration exposure levels of four electrical hammer drills, which were tested with a given range of drill-bit sizes from six drill-bit manufacturers. The measurements examined in this paper are taken from the OPERC HAVTEC database. Vibration exposure levels and time taken to drill a 100 mm deep hole were measured for each combination of drill and bit. The resulting measurements were analysed in accordance with ISO 5349 and the EU Physical Agents (Vibration) Directive. In addition to r.m.s. worst-hand root-sum-of-squares calculations, the number of 100 mm deep holes that may be drilled before reaching the Exposure Action Value (EAV) was also calculated. It was found that in many cases, although the measured vibration magnitudes showed no (or small) differences between the drill bits, the time to drill a 100 mm hole was affected by bit type. Therefore, the number of holes which an operator could drill before reaching the EAV was affected by bit type. These results demonstrate the importance of measuring tool efficiency in addition to vibration magnitude when performing a risk assessment.

1. Introduction

Every day many thousands of workers are exposed to hand-transmitted vibration in their workplace, through the use of hand-held power tools ranging from small percussion drills to large pneumatic breakers. Continued usage of high-magnitude vibrating tools can result in Secondary Raynaud's Disease where the fingers become blanched (Mansfield 2005), also known as Vibration White Finger, a part of Hand-Arm Vibration Syndrome, HAVS (Dong *et al.* 2001, Wasserman 1985). In 2005 the European Union Physical Agents (Vibration) Directive (European Commission 2002) came into force setting limits on the vibration exposure to which a worker may be subject in a working day. The lower threshold, the Exposure Action Value (EAV), is the level at which the employer is required to make changes to minimise both the exposure and risk: this may include a change of tool or a change of working practice. The higher threshold, the Exposure Limit Value (ELV), is the maximum allowable exposure for an employee, assuming that all other measures of risk reduction have been

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implemented. The directive specifies the EAV and ELV vibration magnitudes in terms of an 8-hour equivalent frequency weighted r.m.s. (EAV = 2.5 m/s² A(8), ELV = 5 m/s² A(8)).

Under the Machinery Directive, tool manufacturers are required to provide 'declared' vibration emission values for their tools measured according to the appropriate test code; these values often differ from the values that would be obtained if measured according to ISO 5349, as required by the Physical Agents (Vibration) Directive. In response to demand from the UK construction industry (Edwards & Holt 2005), the trade association OPERC (www.operc.com) have established a freely available online database of in-use tool emission values based on independent tests. The tests have been carried out within the guidelines of ISO 5349-1 (2001) and ISO 5349-2 (2002), using simulated work site conditions. A subset of rotary hammer drill data from the same database has been previously analysed by Mansfield (2006), who compared measured vibration magnitude data with that declared by manufacturers and found that the manufacturers declared values were generally one to two times higher than the measured values.

2. Methodology

The data shown in this paper is taken from the raw measurements used to generate the values presented in the OPERC HAVTEC Database (OPERC). The HAVTEC Database is a freely available database of over 600 tool/accessory summary measurements.

The drill testing was carried out in accordance with ISO 5349-1 (2001). The measurements were conducted with two tri-axial ICP accelerometers and two Larson-Davis IHVM 100 vibration meters, with the analogue output fed into a PC running bespoke data acquisition and analysis software complying with ISO 8041 (2005) (Figure 1). The operator was instructed to drill a 100 mm deep hole in a concrete block (40 N/mm² non-reinforced concrete, containing Derbyshire quartzite aggregate which had been allowed to cure for a minimum of 28 days (BS 206-1 2000)). The tri-axial acceleration was measured on both the front and rear handle, as shown in Figure 2. For each handle, the total weighted r.m.s. vibration was calculated (using W_h from ISO 5349-1 (2001)) and the greatest handle magnitude was then selected. For each combination of drill and drill bit, three operators were each instructed to drill a minimum of five holes each and, if the total test time was less than 60 seconds, continue drilling holes until 60 seconds of measurements were taken. The mean of the 15 or more measurements was recorded as the value for the given drill/drill bit combination in the HAVTEC database. In this paper, the 15 (or more) individual measurements were used for the analysis of each drill/drill bit combination.

Over the course of the OPERC testing, a number of rotary hammer drills have been repeatedly tested using different manufacturers' drill bits. It is these tests which are the focus of this paper, as they give an indication of the difference between different makes of drill bit, and enable a comparison of productivity. Four different drills were used with six different makes/models of drill bits as shown in Table 1 below.

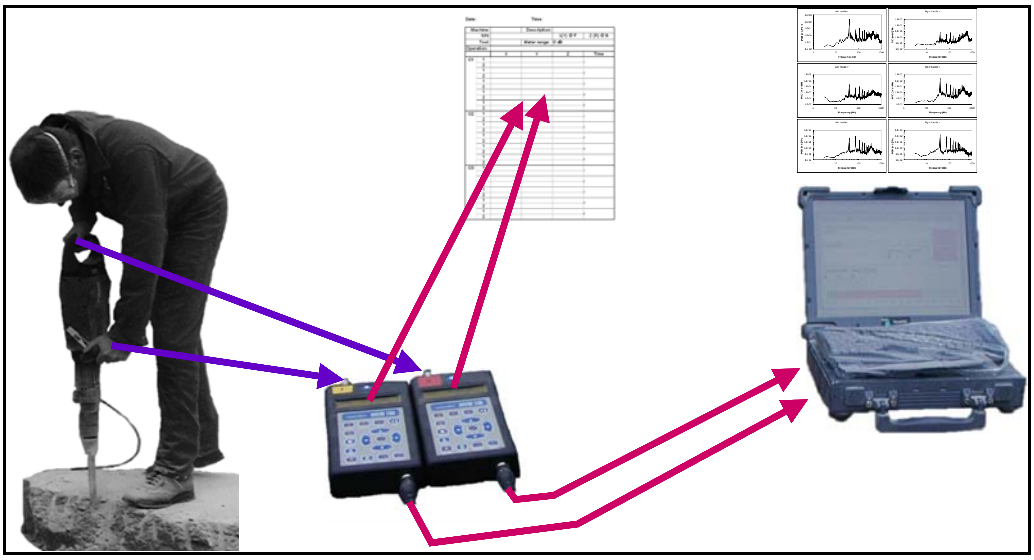


Figure 1: Equipment used in the measurement of vibration magnitude. One tri-axial accelerometer is mounted on each handle of the tool. The r.m.s. vibration magnitudes for each axis are recorded from the data loggers which also act as preamplifiers for the computer based data acquisition system containing advanced signal processing software. (NB participants wore eye protection, safety boots / trainers, and suitable ear plugs / muffs).

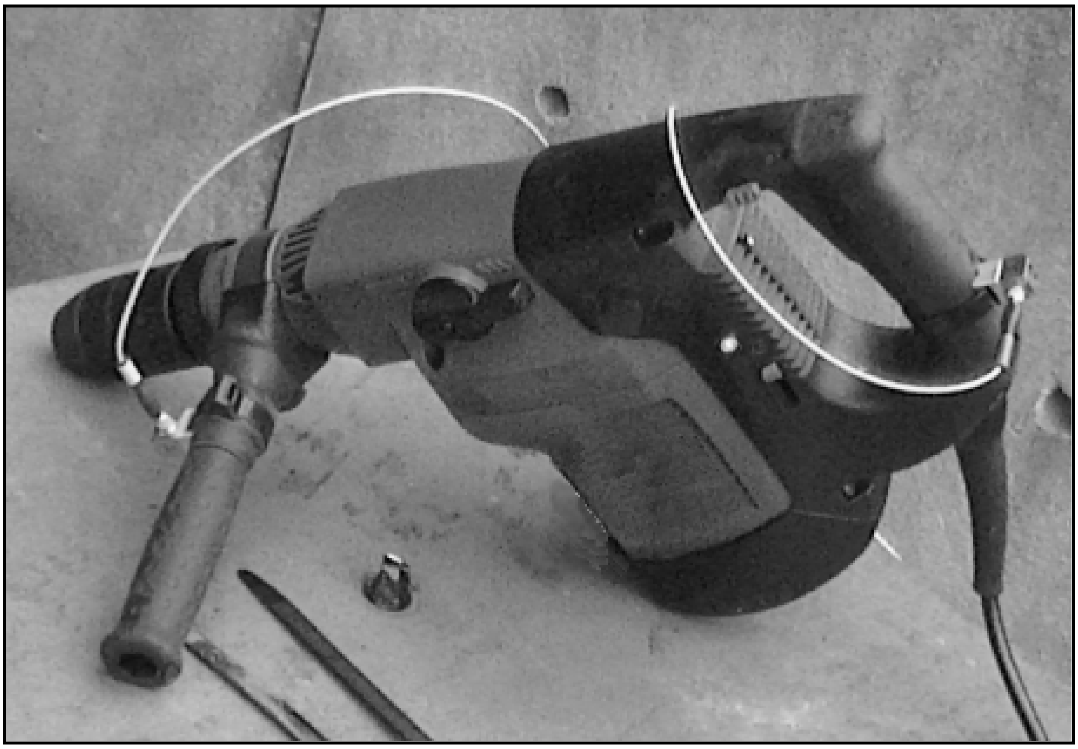


Figure 2: Accelerometer mounting on the front and rear handles. The three axes are set relative to the hand as defined in ISO 5349-1 (2001).

Drill No.	Description	Power	Drill bits tested	Drill bit diameters tested (mm)
1	4 kg SDS+ Rotary hammer drill	110 V ac	1, 2, 4	8, 12, 14, 18, 20
2	4 kg SDS+ Rotary hammer drill	Battery	1, 2, 4, 5	6, 8, 10
3	8 kg SDS Max Rotary hammer drill	110 V ac	1, 2, 3	20, 22, 24, 25, 26, 28, 30, 32, 40
4	6 kg SDS Max Rotary hammer drill	110 V ac	1, 2, 3, 6	16, 20, 25

Table 1: Specification of drills used

3. Results and analysis

The mean of the repeated measurements of the weighted worst hand acceleration values are shown in Figures 3A, 4A, 5A and 6A for each combination of drill, drill bit manufacturer and drill bit size. It can be seen that, generally, the acceleration increases slightly with drill diameter - as also reported by Mansfield (2006). In addition to the acceleration measurements, the time taken to drill a 100 mm deep hole was also recorded (the time has been normalised to 100 mm for the 6 mm diameter drill bits used with Drill 2, as the bits were not long enough for 100 mm holes). With the vibration acceleration and drilling time known, it was possible to calculate the number of 100 mm deep holes that may be drilled before reaching the Exposure Action Value (EAV), defined as 2.5 m/s² (European Commission 2002), as follows:

Time to EAV, $T_{EAV} = \dfrac{8 \times 2.5^2}{a_{r.m.s.}{}^2}$

Number of 100 mm deep holes that may be drilled before reaching the EAV = $\dfrac{T_{EAV}}{T_{1\,hole}}$

where $a_{r.m.s.}$ is the weighted worst-hand vibration magnitude, and T_{1hole} is the time taken to drill one hole (or the mean of a number of repeated measurements).

The data was analysed to determine whether it is normally distributed. Skewness, Kurtosis and the One-sample Kolmogorov-Smirnov statistical tests were used, and these tests indicated that the data was normally distributed and not skewed, thus allowing the use of parametric analysis methods. The data was analysed using a multivariate Analysis of Variance (ANOVA) with a Tukey HSD Post-hoc test where required. The ANOVA and Post-hoc tests showed whether or not the different drill bits (for each given drill) are significantly different. A summary of the findings is shown in Table 2. For Drill 1 (4 kg SDS+), there was no significant difference between the different makes of drill bit for vibration magnitude, therefore the data for the different manufacturers may be combined as shown in Figure 3B. However, there was a significant difference between drilling time and the number of holes (a function of vibration and drilling time), where drill bit 2 was the better performing bit across the full range of diameters. For Drill 2 (4 kg battery powered SDS+) there was no significant difference between bits 1 and 2 for vibration, time and number of holes. In addition, drill bit 4 was not significantly different to the other drill bits (i.e. 1, 2 and 5) for time. With Drill 3 (8 kg SDS Max) there was no significant difference between bits 1 and 3 for vibration magnitude, but there was a significant difference for time and number of holes that may be drilled. For the other drill bits there was a significant difference for vibration, drilling time and number of holes that may be drilled. Considering the two drill bits that were tested with Drill 4 (6 kg SDS Max) across the whole range of diameters (drill bits 3 and 6), there was a significant difference for vibration magnitude, time to drill a hole but no significant difference for the number of holes that may be drilled before reaching the EAV.

A further examination of Table 2 shows the performance of each individual drill bit. For the vibration measurement, no one bit is consistently higher or lower than any other bit, other that drill bit 6 which was the highest; however, it was only tested with one drill. For the time measurement, drill bit 2 is consistently the slowest across all four drills. Drill bit 4 is consistently the fastest to drill a 100 mm hole with Drills 1 and 2 and drill bit 3 is the fastest with Drills 3 and 4.

For those cases where they were tested with many sizes, drill bits 1 and 2 were generally superior to bits 3, 4 and 5, when considered in terms of the combined performance / vibration magnitudes (i.e. the number of holes that could be drilled before reaching the EAV).

The ANOVA and Post-hoc tests also showed the significant differences between drill bits as a function of drill diameter (for each given drill), the results from this analysis are shown in Table 3. The vibration, drilling time and number of holes varies significantly with drill bit size for the majority of the drill bits tested. The exceptions are Drill 1/time (no significant difference below 14 mm diameter), Drill 3/vibration (no significant difference below 40 mm diameter) and Drill 3/time (no significant difference below 25 mm diameter).

4. Conclusions

Four different models of rotary hammer drill were tested using a range of different sized drill bits from six manufacturers. Tri-axial vibration magnitude was measured, along with the time to drill a 100 mm deep hole. From the measurements, the trigger time to reach the EAV (2.5 m/s^2) was calculated, and this was used to determine the number of 100 mm holes that may be drilled before reaching the EAV. It was found that for Drill 1, there was no significant difference between the vibration levels, but there was a significant difference between drilling time. For the battery powered drill (Drill 2), there was no significant difference between bits 1 and 2; however, there was a significant difference between the other bits for the vibration, drilling time and the number of holes that may be drilled. For Drills 3 and 4, there were significant differences between all of the drill bits for the time taken to drill a 100 mm deep hole. It was also found that with a few exceptions, the vibration, drilling time and number of holes that may be drilled varied significantly with drill bit diameter, with vibration and drilling time increasing with increasing bit size, and the number of holes decreasing with increasing bit size.

These results show that, whilst different makes of drill bit may produce similar levels of vibration, the time taken to drill a hole may vary significantly or vice versa. This has implications when calculating the number of holes that may be drilled before reaching the EAV, as the calculation is a function of time and magnitude squared. Therefore, it is recommended that productivity measurements are taken in addition to vibration magnitude when testing vibration exposure of hand held rotary hammer drills.

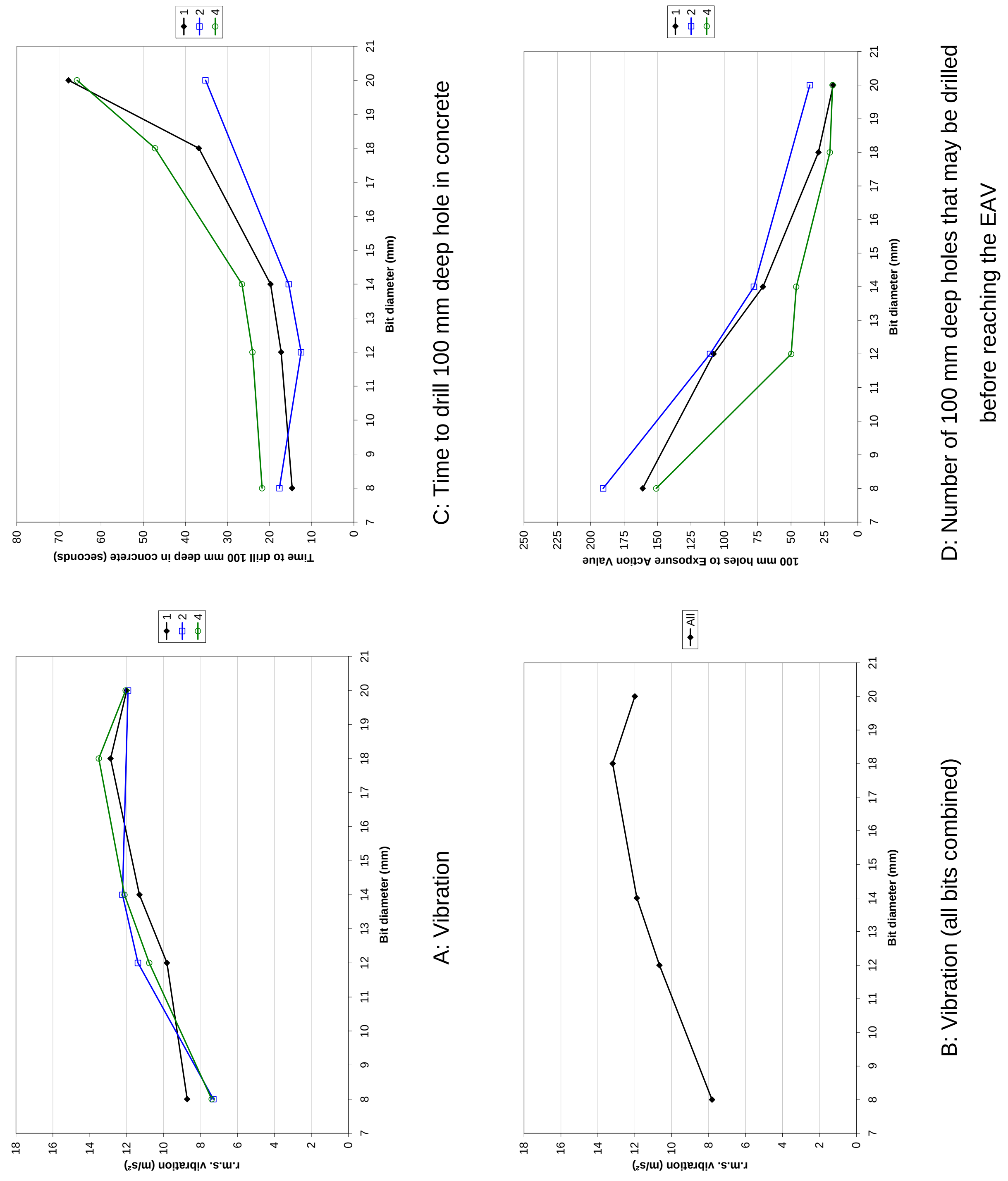
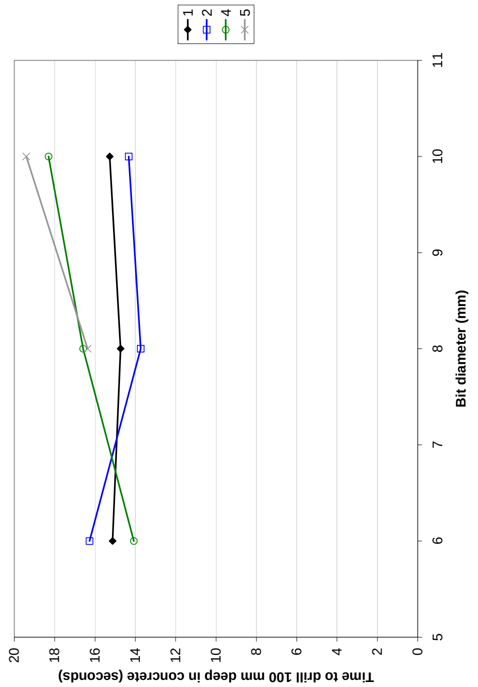
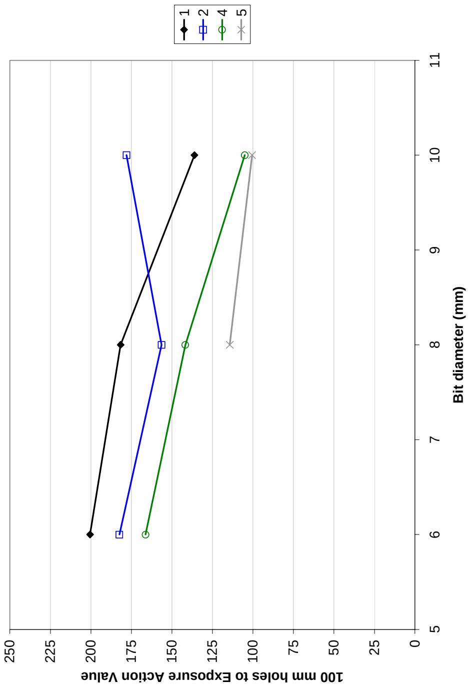


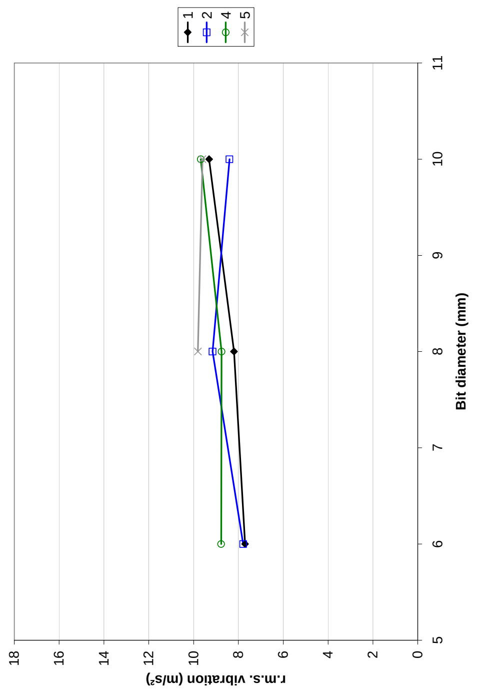
Figure 3: Measured results for Drill 1 (4 kg SDS+) using Drill Bits 1, 2 and 4. For the vibration measurement (A), the three drill bits are not significantly different (see Table 2) and thus the data may be combined as shown in (B).



B: Time to drill 100 mm deep hole in concrete



C: Number of 100 mm deep holes that may be drilled before reaching the EAV



A: Vibration

Figure 4: Measured results for Drill 2 (4 kg SDS+ Battery Powered) using Drill Bits 1, 2, 4 and 5.

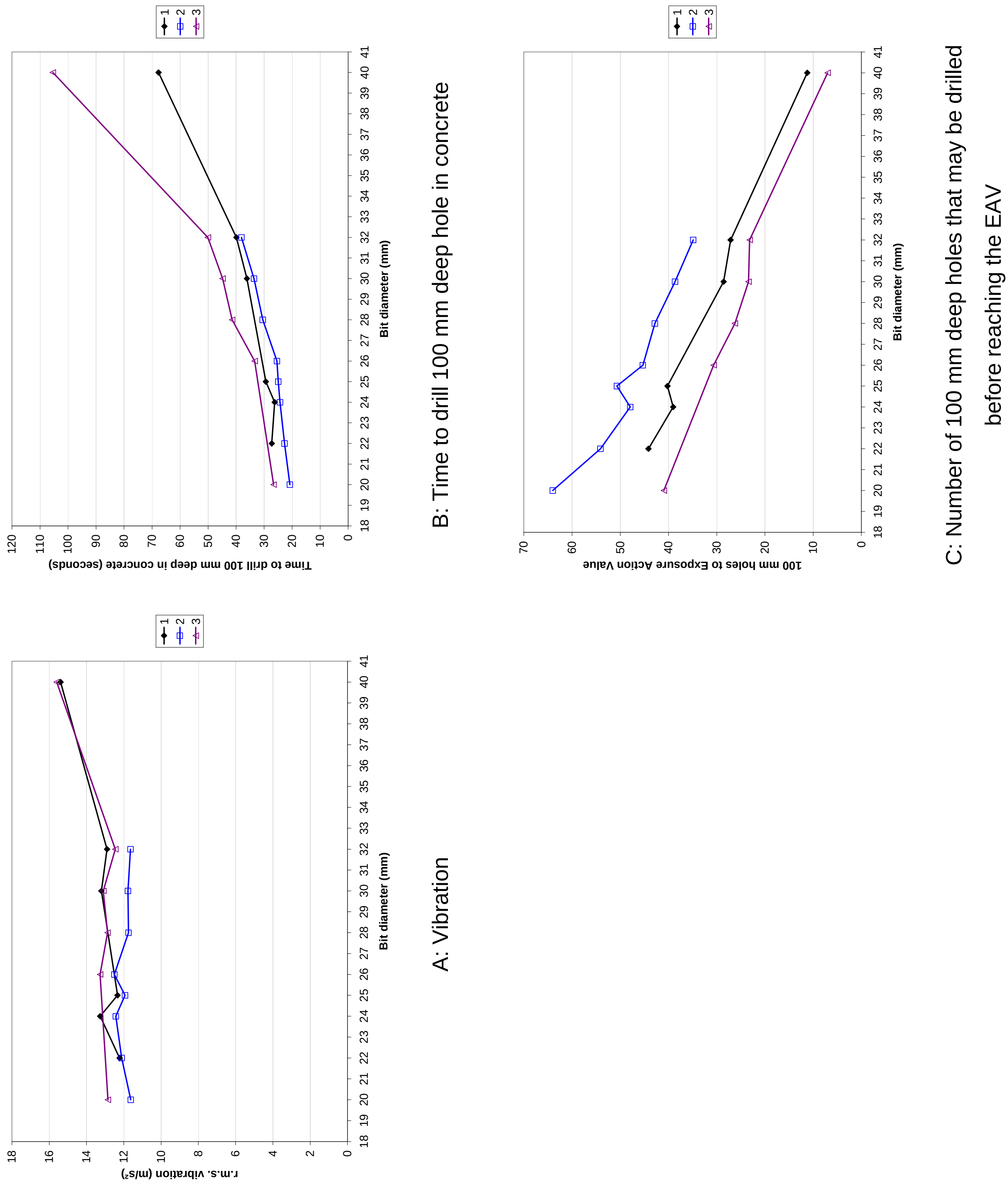


Figure 5: Measured results for Drill 3 (8 kg SDS Max) using Drill Bits 1, 2 and 3.

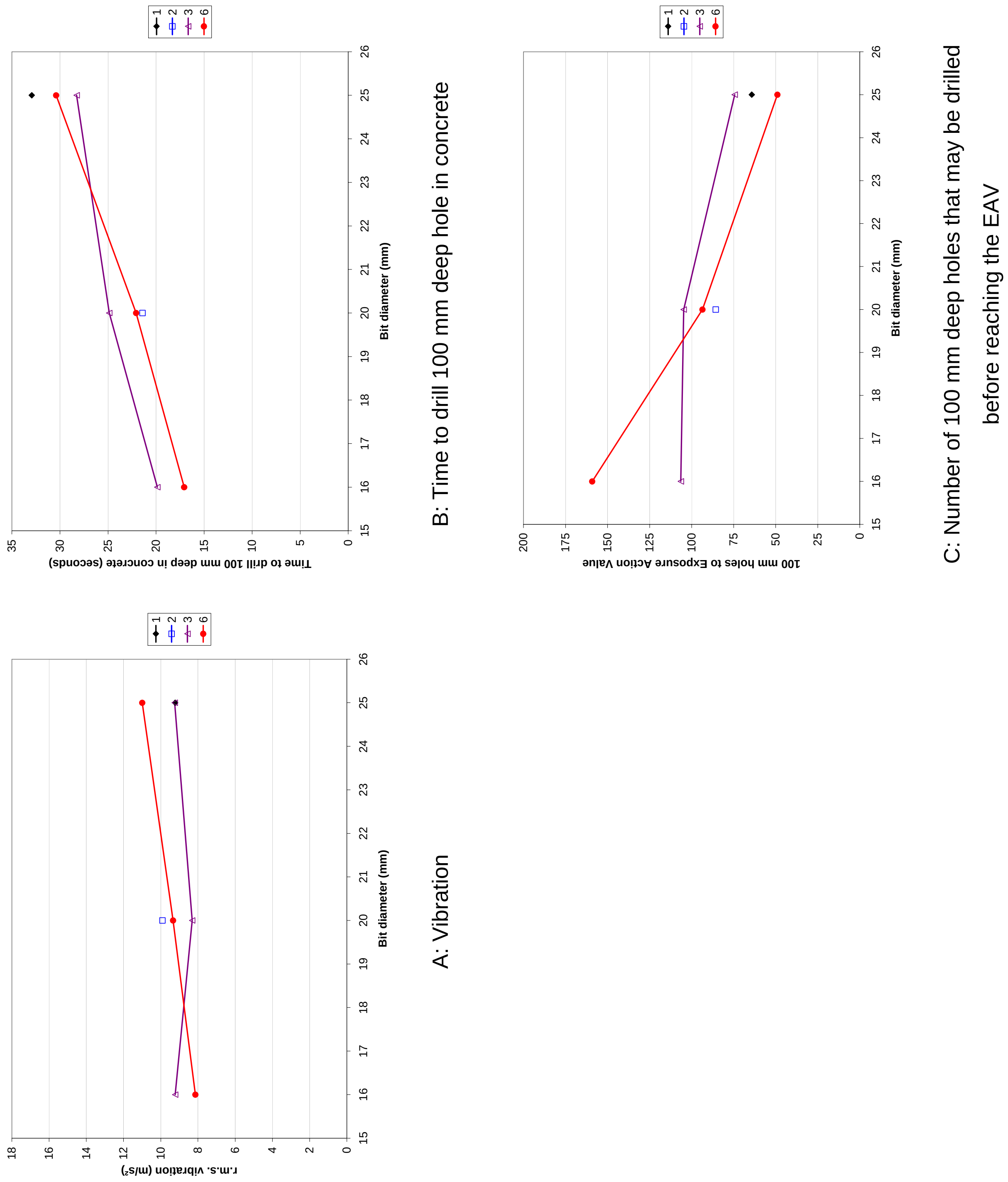


Figure 6: Measured results for Drill 4 (6 kg SDS Max) using Drill Bits 1, 2, 3 and 6.

Drill	Vibration		Time for 100 mm hole		Holes to EAV	
	Significant	Non-significant	Significant	Non-significant	Significant	Non-significant
1	-	No significant difference between all bits.	1 > 2 1 < 4 2 < 4	-	1 < 2 1 > 4 2 > 4	-
2	1 < 4 1 < 5 2 < 4 2 < 5 4 < 5	1 & 2	1 < 5 2 < 5	1 & 2 1 & 4 2 & 4 4 & 5	1 > 4 1 > 5 2 > 4 2 > 5 4 > 5	1 & 2
3	1 > 2 2 < 3	1 & 3	1 > 2 1 < 3 2 < 3	-	1 < 2 1 > 3 2 > 3	-
4	2 > 3 3 < 6	1 & 2 1 & 3 1 & 6 2 & 6	1 > 2 1 > 3 1 > 6 2 < 3 2 < 6 3 > 6	-	1 < 2 1 < 3 1 < 6 2 < 6	2 & 3 3 & 6

Table 2: Significant and non-significant relationships for the drill bits tested (the relationship is considered to be significant if $p < 0.05$).

Drill	Vibration	Time for 100 mm hole	Holes to EAV
1	Significant difference (p<0.05)	Significant difference above 14 mm (p<0.05)	Significant difference (p<0.05)
2	Significant difference (p<0.05)	Significant difference (p<0.05)	Significant difference (p<0.05)
3	No significant difference below 40 mm (p>0.05)	Significant difference above 25 mm (p<0.05)	Significant difference (p<0.05)
4	Significant difference (p<0.05)	Significant difference (p<0.05)	Significant difference (p<0.05)

Table 3: Significance of drill bit diameter as a function of vibration, drilling time and number of holes before reaching the Exposure Action Value.

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