

1.0 –Survey Correction Procedures SAG / MSA

Some of the information detailed below contains values which could be used as a guide when creating company policy. These are **not definitive** and there is no set industry standard. It is very important that individual companies have their own **Policies, Procedures** and **Guidelines** in place, clearly detailing the way that they handle **SAG** correction. These should be company specific, and it is essential that they are distributed among relevant personnel, understood and closely followed.

2.0 - SAG

- SAG occurs when a BHA bends under its own weight when positioned between two points of stabilisation
- The degree of bending is affected by:
 - Hole Size
 - Stabiliser Size
 - Distance between points of stabilisation
 - Tubular OD & ID – Stiffness
- SAG causes MWD sensor misalignment in relation to the borehole
- BHA SAG accounts for up to 80% of wellbore TVD position uncertainty

3.0 -SAG Correction Considerations

3.1 - Inclination range

- From 0-3° the potential correction will likely be invalid due to the difficulty with finding the point at which the top of the BHA contacts the wellbore, this is due to the hole not having a defined highside.
- SAG should be applied when the inclination is >3° however >5° is also acceptable in certain circumstances

3.2 - Innova Engineering BHA Entry

- Assemblies containing motors or turbines, which have a bend setting, have to be carefully dealt with, as the toolface (TF) the bend is aligned on during the survey has an effect on the correction
- This can complicate matters, and introduce errors if not handled correctly
- The corresponding correction for bends $\leq 1^\circ$ are generally small enough that assemblies can be modelled, for SAG purposes, with no (0°) bend. It should be noted that doing this will mean that you do not get a predicted "BUR Slide" in the BHA Analysis output.
- For bends $> 1^\circ$ the assembly more often than not should be correctly modelled in Engineer

3.3 - Difference between the MWD sensor TF & Motor TF (TF Offset)

- Extra care must be taken to ensure that the method of calculating the TF offset is correct and done as accurately as possible in the field
- Stringent policy should be in place including field paperwork which details the measurements and is signed by the DD, MWD engineer and Company Representative
- Apart from the obvious directional implications, an incorrect TF offset will introduce errors if used in the correction

3.4 - BHA Diagrams and lengths

- BHA diagrams created in the field should be accurate and contain all of the relevant data required to precisely model the assembly in Engineer
- Required measurements should be clearly detailed
- It should be unmistakably stated what is meant by each measurement e.g. what exactly do you mean by stabiliser blade length
- A copy of this paperwork should always be sent to the office

3.5 - ISCWSA Error Model Assignment

- When SAG correction is used it is important to assign the correct error model in Well Seeker Pro, to ensure accurate anti-collision and error ellipse calculations

4.0 - Pre-job Planning

- Create a pre job BHA in the office and send to the field
- Once all measurements have been taken in the field of the actual BHA, the field engineers should update their BHA in Engineer and send in a copy of their BHA sheet to the office
- **DO NOT SEND AN ENGINEERING PROJECT FILE FROM THE FIELD TO THE OFFICE**
- The engineers in the office should update Engineer **independently**, using the detailed BHA they receive from the field. When checking someone else's inputs it is too easy to miss mistakes
- Once the field & office have the accurate BHA modelled, run the calculation over a set inclination range for fixed parameters. Field and office outputs should be compared and match exactly.
- Any discrepancies between the 2 sets of test data should be addressed until everything matches

5.0 - Drilling

- MWD Engineers should always keep a record of the RAW (uncorrected) inclinations in order to verify any corrections applied
- Field engineers should run the RAW surveys through Engineering as they get them, and should note the exact correction used - usually on a survey sheet
- DD's should send in corrected surveys on a daily basis (or as per company policy)
- MWD engineers should send in RAW, uncorrected surveys, including the motor bend TF recorded for each individual survey if relevant

- Office engineers should use RAW data to independently run the SAG calculation and check this against the corrected survey received from the DD.
- Any discrepancies should be addressed immediately, and rechecked until both sets of data match

6.0 - Rotational Shots

- Carried out to correct for any tool face dependant errors such as sensor bias or sensor misalignment.
- Four surveys are taken, one in each of the four quadrants (0-90°, 90-180°, 180-270° & 270-360°)
- For a correctly centred sensor, all four surveys should be identical. This is rarely the case.
- If they are not identical, a correction can be calculated based on the data from the four surveys; this correction is applied to the X and Y axis accelerometers and magnetometers.
- Rotational shots should only be taken if the well bore inclination is >5°, every time a new sensor or BHA is run. Consideration should be given to hole conditions and the time taken to acquire the data.
- This is a specialist application which should only be done by a survey specialist and not a correction which should be done in the field
- It is questionable whether or not this process is worthwhile as there are no error models relating to this correction and many companies including Shell have stopped using it
- Innova can provide this service if requested

7.0 - Multi Station Analysis

- A statistical method to correct for sensor misalignment and bias
- Careful consideration has to be given to the dataset used as surveys which are out of spec can have a big effect on the results
- All surveys are analysed and a monte-carlo analysis run. A pseudo bias and scale factor is applied to X,Y Z axis accelerometers and magnetometers.
- This is a specialist application which should only be done by a survey specialist and not a correction which should be done in the field
- Innova can provide this service if requested

8.0 - SAG Module

This section will deal with the SAG module within Innova Engineering and will detail the steps required to run SAG analysis.

8.1 - Required Inputs

In order to run SAG, the following inputs are required.

- **Units:** Firstly, ensure that all of the units are correctly selected, based on requirements
- **Well Geometry:** The wellbore geometry tells the program the size of hole that the assembly is in.
- **Mud Weight**
- **Survey Selection:** Actual Surveys, Well Plan Surveys or RAW Surveys (SAG can be run on any of these, but at least one must be populated)
- **Sensor Offset:** distance from Bit to MWD Sensor – Required for SAG but not used in BHA Analysis calcs.
- **Drill String:** This does not need to include any more than ~30m (100ft) of assembly beyond the last point of stabilisation. Beyond this point the remainder of the drill string will be lying on the low side of the hole and is not considered in the calculation.

The screenshots show the following interface elements:

- Units Menu:** A dropdown menu with 'Mud' selected, showing a list of units including PPG, SG, 8.2, Surveys, Eng, and OD (in).
- Well Geometry Table:**

Type	MD (ft)	TVD (ft)	ID (in)
1 Casing	1000.00	988.616	12.500
2 Open Hole	2000.00	1942.088	12.250
3			
- Survey Corrections:** A table with 'Offset (ft)' and 'Inc Start' columns. The 'Offset (ft)' cell contains '0.00' and is highlighted with a red box.

Extra care should be taken when adding the stabiliser data (including motor stab sleeve).

- **Stab OD:** The outside diameter of the stabiliser
- **Stab Blade Length:** The length of the stabiliser blade that will be in contact with the side of the hole - **WATCH YOUR UNITS, THIS IS INPUT AS INCHES**
- **Stab Dist from Bottom:** The distance from the Pin end shoulder to the bottom of the stab blade

SN	
Stab OD (in)	12.125
Stab Blade Length (in)	15.350
Stab Dist From Bottom (m)	0.500
Connection Top	
Connection Bottom	
Stab Blade Width (in)	3.000

These are the 3 main inputs required to model a stabiliser. None of the other stabiliser component details affect the calculation.

8.1.1 – Bit Formation Index (BFI)

The screenshot shows the 'Component Details' form for a BHA Weight (Buoyed) of 949 kips (Vertical). The form includes the following fields:

- G1
- Gauge OD (in)
- TPA (sq in)
- Connection Top
- Bit Formation Index (B-1)
- Bit Type
- Torque Yield (ft-c)

Buttons at the bottom include 'Insert Before', 'Insert After', 'Move Up', and 'Move Down'.

When a BHA analysis calculation is run, the program calculates the theoretical dogleg generated by the assembly, based on all the input parameters. This will be represented as a build or a drop.

The bit formation Index is an important input (located in the bit component details) as this determines the proportion of dogleg associated with build and walk rate. It effectively models the tendency of the bit to walk.

The BFI is input as a value between 0 and 1 and affects the calculation as follows.

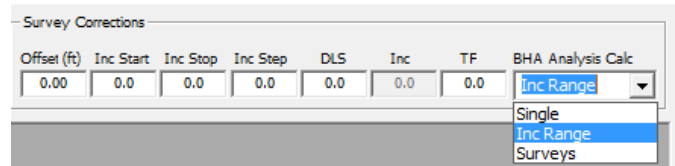
- **Build Up Rate (BUR) = DLS * Cos (BFI)**
- **Walk Rate (WR) = DLS * Sin (BFI)**

With a BFI of zero (default), the walk rate will be 0 and all the dogleg will be attributed to build or drop. With a BFI of 1, the build rate will be 0 and all the dogleg will be attributed to walk. The more aggressive the bit, the higher the tendency to walk and therefore the higher the BFI.

For tri-cone bits, a BFI range of 0 to 0.3 is typical, while for more aggressive PDC bits 0.2 to 0.5 (or higher) can be modelled.

8.2 - Setup

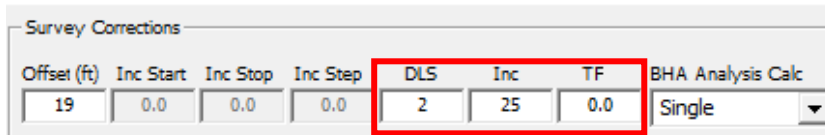
The **Survey Corrections** section of the **Surveys** Tab, is where the user can select the way they want to run the SAG correction.



8.2.1 - Single

Selecting **Single** allows the user to calculate a SAG correction based on a single inclination.

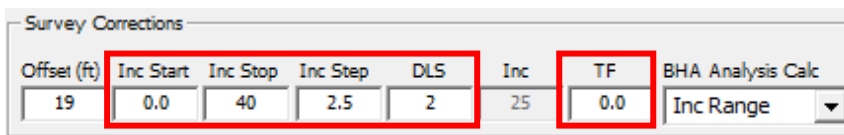
- **Inc:** Inclination that the user requires SAG results for
- **DLS:** Dogleg (°/30m or °/100ft depending on units selected). The program will use the dogleg to simulate hole curvature which affects the results. Zero represents a tangent.
- **TF:** The Toolface of the motor bend during the survey (if the motor does not have a bend modelled in Engineering, this input will not have any effect on the calculation)



8.2.2 - Inc Range

Selecting **Inc Range** allows the user to calculate SAG over a range of inclinations

- **Inc Start:** Initial Inclination
- **Inc Stop:** Final Inclination
- **Inc Step:** Step change in inclination between the initial and final. A step change of 2.5° will calculate SAG every 2.5° between the selected range.
- **DLS:** Dogleg (°/30m or °/100ft depending on units selected). The program will use the dogleg to simulate hole curvature which affects the results. Zero represents a tangent.
- **TF:** The Toolface of the motor bend during the survey (if the motor does not have a bend modelled in Engineering, this input will not have any effect on the calculation)



8.2.3 - Surveys

Selecting Surveys allows the user to calculate SAG on Actual Surveys, Well Plan Surveys or RAW Surveys, depending on what is selected

- **TF:** The Toolface of the motor bend during the survey (if the motor does not have a bend modelled in Engineering, this input will not have any effect on the calculation)

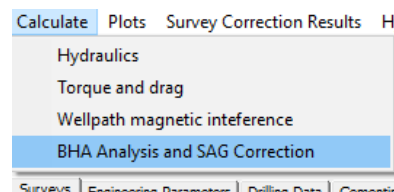
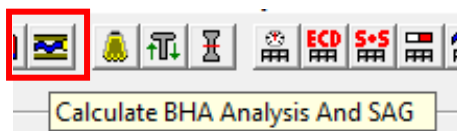
Survey Corrections							
Offset (ft)	Inc Start	Inc Stop	Inc Step	DLS	Inc	TF	BHA Analysis Calc
19	0.0	40	2.5	2	25	0.0	Surveys

When **Surveys** is selected in **BHA Analysis Calc**, the calculation will run against whichever survey is selected in the **Survey Selection**.

Survey Selection	
Raw Surveys	▼
Actual Surveys	
Well Plan Surveys	
Raw Surveys	

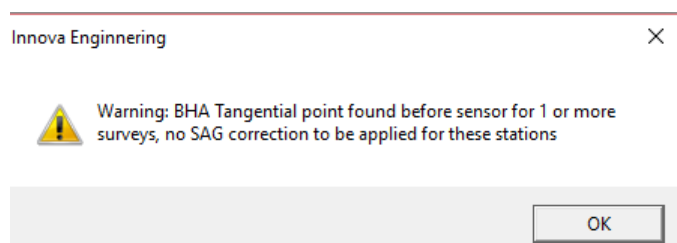
8.3 - Running the Calculation

Once the user has completed all the required inputs the calculation can be run. To do this, select either the icon displayed below, or select **Calculate - BHA Analysis and SAG Correction**



8.3.1 - Warning

The BHA Tangential Point, is the point above the last stabiliser where the assembly touches the side of the hole. Anything above this point will be lying against the side of the hole and will therefore not be subjected to SAG. In this situation a warning box will appear. It is important to note that the tangential point changes depending on the curvature of the hole, and in some instances when running the calculation there will be some stations that will require correction and others that will not. Engineering runs through all of these calculations and assigns a 0° correction to those that do not.



8.3.2 - Dealing with Motor Bend Toolface

If the motor bend is not being modelled in Engineering i.e. Bend angle is 0° in the motor component details, then it is possible to SAG correct all required stations in one go. If however, the motor bend is being modelled, then each station has to be SAG corrected individually, assigning the relevant Toolface for each survey. This is more labour intensive and therefore more susceptible to errors.

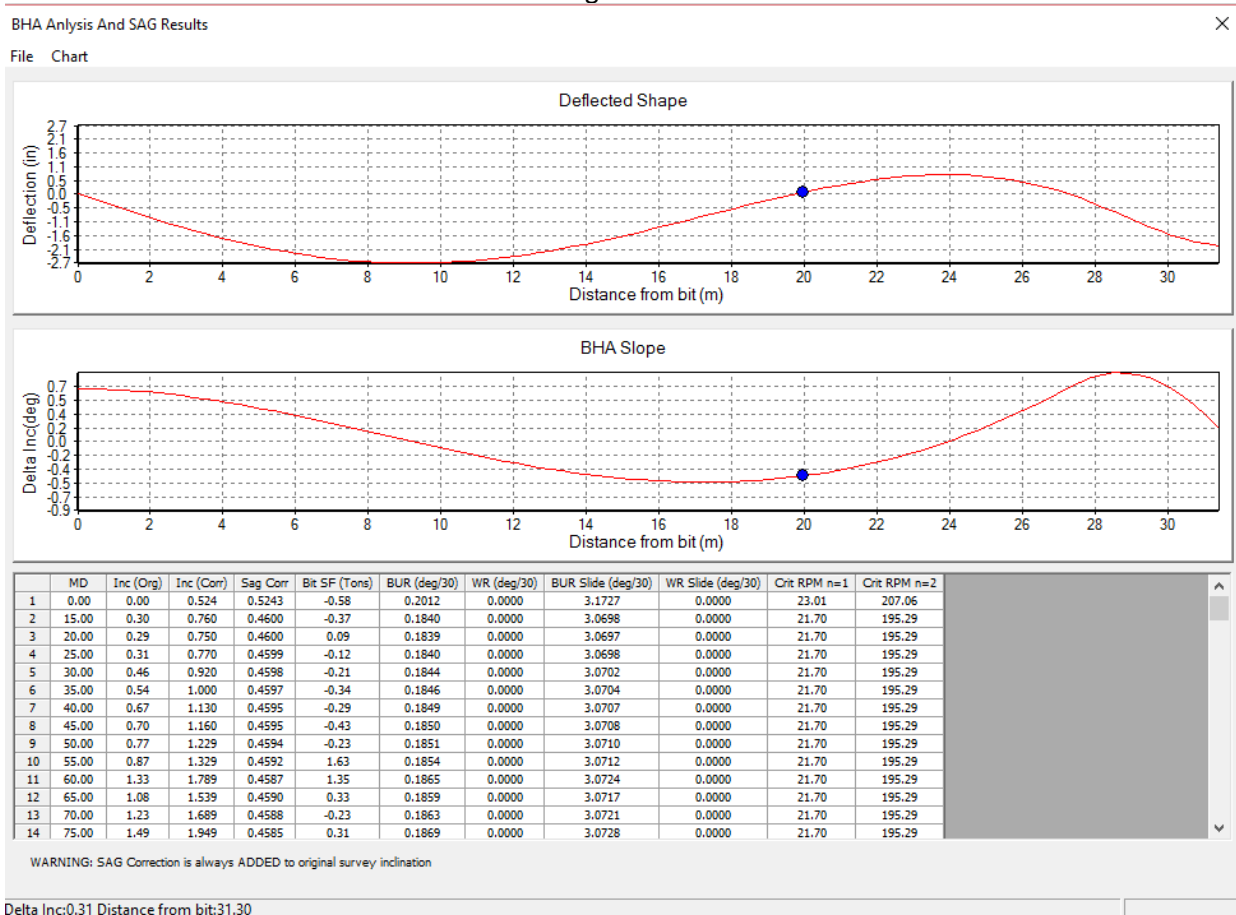
When the bend is not being modelled, the addition of new stations has no effect on the historic corrections. This is not the case when modelling the bend. When a new survey station is added and the correction run, the program runs the correction against all of the previous stations using the assigned toolface. Since every station will likely have been measured on a different toolface, it is possible that the program may change some of the previous corrections based on the new toolface. For this reason it is important to carefully note the correction at each new station as it is calculated, and understand why you may see a difference when looking at earlier corrections.

8.3.3 - Output

The following outputs are displayed in the BHA Analysis and SAG Results

- **Deflected Shape:** Shows the deflected shape of the BHA. The blue dot represents the sensor position. Note that the displayed plot always represents the final station.
- **BHA Slope:** Shows the slope of the BHA and relates to the correction. The blue dot represents the sensor position. The displayed plot always represents the final station.
- **MD:** Measured Depth of Station.
- **Inc (Org):** The uncorrected inclination.
- **Inc (Corr):** The SAG corrected inclination.
- **Sag (Corr):** The SAG correction to be applied to the uncorrected inclination.

$$\text{Inc (Org)} + \text{Sag (Corr)} = \text{Inc (Corr)}$$
- **Bit SF:** Sideforce at the bit.
- **BUR:** Predicted Rotary Build Rate.
- **WR:** Predicted Rotary Walk Rate.
- **BUR (Slide):** Predicted Build Rate Sliding. If the motor has a 0° bend, this column will not display.
- **WR (Slide):** Predicted Walk Rate Sliding. If the motor has a 0° bend, this column will not display.
- **Crit RPM:** The theoretical RPM that excites the natural frequency of the drill string. These RPM's should be avoided when rotating.



NOTE: SAG corrections are always ADDED

When running the SAG calculation on RAW surveys, in addition to the BHA Analysis and SAG Results being generated, the **Inc SAG** and **Delta Inc** columns will be populated. These will be empty until the calculation has been run, at which point they will be populated.

- **Inc SAG:** The SAG corrected inclination
- **Delta Inc:** The SAG correction to be applied to the uncorrected inclination

Innova Engineering

File Units Options Tools Calculate Plots Survey Correction Results Hydraulics Results TAD Results Help

Project Name: 12.25" Motor Assembly Description:

Drilling, Well Geometry and Fluids Surveys Engineering Parameters Drilling Data Cementing

Vertical Section: Az: 0.000, Origin NS: 0.000, Origin EW: 0.000

Survey Selection: Raw Surveys

Raw Survey Data: HL Ref: 49.9500, Dip: 59.571, TAC: 6.600, Grid Conv: -0.24000, Declination: 6.360, North Ref: Grid

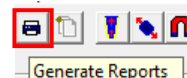
Survey Corrections: Offset (m): 19.94, Inc Start: 0.0, Inc Stop: 0.0, Inc Step: 0.0, DLS: 0.0, Inc: 0, TF: 0.0, BHA Analysis Calc: Surveys

	MD (m)	GK	GY	GZ	HX	HY	HZ	Inc	Azi	Inc SAG	Azi SCC	HL SCC	Dip SCC	HL	GT	Dip	Rot	Delta Inc	Delta Azi	TVD (m)	NS
1	0.00									0.524							0.524		0.00	0.0	
2	340.10	0.0090	-0.0915	0.9940	0.0370	-0.2080	0.4618	5.28	362.87	5.548	362.86	49.9031	59.6857	50.7824	0.9982	80.1462	84.3824	0.1603	0.0141	339.62	15
3	380.00	-0.0705	0.0525	0.9945	-0.1860	0.1044	0.4636	5.05	360.38	5.318	360.35	49.9061	59.6771	51.0214	0.9984	80.1305	36.6743	0.2679	0.0250	379.36	19
4	395.60	-0.0865	0.0240	0.9945	-0.2095	0.0209	0.4633	5.16	358.37	5.428	358.34	49.9110	59.9104	50.8826	0.9985	80.4578	15.5070	0.2681	0.0322	394.89	20
5	408.90	0.0450	0.0770	0.9945	0.0809	0.1978	0.4618	5.12	359.83	5.388	359.81	49.9431	59.5875	50.8827	0.9985	80.0880	59.6973	0.2680	0.0235	408.14	21
6	414.90	-0.0145	0.0785	0.9955	-0.0381	0.2164	0.4651	4.58	7.02	5.035	7.02	50.0380	59.3635	51.4385	0.9987	80.1241	79.5347	0.4547	0.0029	414.12	22
7	425.70	-0.0335	-0.0710	0.9955	-0.1073	-0.1864	0.4629	4.51	10.60	4.965	10.62	49.8041	59.9181	51.0417	0.9986	80.5823	-64.7406	0.4548	-0.0201	424.89	23
8	443.60	-0.0705	-0.0125	0.9960	-0.2241	0.0099	0.4603	4.11	17.60	4.604	17.64	50.0497	59.3417	51.2076	0.9986	59.9921	-10.0543	0.4943	-0.0399	442.74	24
9	453.10	0.0005	-0.0660	0.9965	-0.0846	-0.2241	0.5021	3.79	25.32	4.285	25.47	50.5895	58.1730	50.5895	0.9987	80.9276	89.5659	0.4947	-0.2536	452.21	25
10	462.70	0.0370	-0.0495	0.9965	0.0355	-0.2051	0.4255	3.55	30.64	4.045	30.52	49.0524	61.6886	47.3704	0.9984	80.7316	53.2228	0.4950	0.1198	461.79	25
11	472.50	0.0555	-0.0195	0.9965	0.1520	-0.1513	0.4636	3.38	29.32	3.875	29.43	49.2768	61.1269	51.0801	0.9982	82.0955	19.3590	0.4952	-0.1059	471.58	26
12	481.70	0.0555	-0.0150	0.9970	0.1787	-0.1564	0.4541	3.30	30.17	3.795	30.23	50.2321	58.8257	51.2441	0.9987	59.3972	15.1240	0.4953	-0.0580	480.76	26
13	491.30	-0.0105	0.0520	0.9970	0.0916	0.2142	0.4512	3.05	38.11	3.546	38.17	49.9230	59.6295	50.7770	0.9984	80.1348	78.5842	0.4956	-0.0578	490.35	27
14	501.10	-0.0050	-0.0540	0.9970	-0.1714	-0.1586	0.4519	3.11	44.84	3.660	44.93	49.8866	59.7079	50.8638	0.9985	80.2915	-84.7099	0.5502	-0.0885	500.13	27
15	510.40	0.0260	0.0420	0.9975	0.2293	0.0450	0.4515	2.83	49.99	3.381	50.09	49.7508	59.9985	50.8402	0.9987	80.6456	-14.8783	0.5505	-0.0985	509.42	27
16	520.30	0.0490	-0.0210	0.9970	0.0465	-0.2351	0.4493	3.06	57.77	3.610	57.88	49.9741	59.5198	50.9261	0.9984	80.0989	23.1986	0.5503	-0.1056	519.31	28
17	530.10	-0.0050	0.0525	0.9970	0.2032	0.1271	0.4493	3.03	65.21	3.580	65.34	49.8453	59.7899	50.9278	0.9984	80.4534	84.5597	0.5503	-0.1259	529.09	28
18	539.70	0.0100	-0.0600	0.9965	-0.2157	-0.1121	0.4460	3.49	72.77	4.040	72.90	49.9277	59.6170	50.7972	0.9984	80.1629	80.5377	0.5498	-0.1264	538.68	28
19	549.50	0.0300	-0.0595	0.9965	-0.1923	-0.1542	0.4449	3.83	78.10	4.379	78.24	49.9999	59.4688	50.8622	0.9987	80.0112	63.2427	0.5494	-0.1368	548.46	28
20	559.00	0.0430	-0.0565	0.9960	-0.1765	-0.1754	0.4442	4.08	82.01	4.629	82.17	50.0352	59.3984	50.9166	0.9985	59.9572	52.7266	0.5491	-0.1601	557.94	28
21	568.90	-0.0095	-0.0755	0.9955	-0.2501	0.0260	0.4427	4.37	87.75	4.919	87.92	50.0163	59.4382	50.9179	0.9984	60.0194	-82.8283	0.5487	-0.1734	567.81	29
22	577.30	0.0045	-0.0825	0.9950	-0.2552	0.0070	0.4424	4.75	93.04	5.379	93.26	50.0469	59.3804	51.0789	0.9984	60.0529	86.8779	0.6291	-0.2229	576.18	29
23	586.70	-0.0010	-0.0910	0.9945	-0.2527	0.0487	0.4406	5.23	97.86	5.859	98.12	49.9677	59.5364	51.0294	0.9987	80.2371	-89.3704	0.6285	-0.2552	585.55	29
24	596.60	0.0260	-0.0980	0.9935	-0.2694	-0.0029	0.4384	5.83	100.93	6.458	101.20	49.9647	59.5426	50.9894	0.9987	80.2311	75.1414	0.6278	-0.2709	595.40	28
25	606.10	0.1070	-0.0405	0.9920	-0.1622	-0.2058	0.4347	6.58	103.12	7.207	103.38	49.8831	59.6978	50.9274	0.9986	80.2828	20.7319	0.6270	-0.2618	604.84	28
26	615.70	0.1265	-0.0295	0.9900	-0.1457	-0.2263	0.4329	7.47	104.12	8.096	104.42	49.1026	59.2866	50.9753	0.9985	59.8912	13.1269	0.6260	-0.2964	614.37	28

Insert Before Insert After Delete

8.3.4 - Reports

Once a calculation has been run, if required the user can generate a report. This can be done by either selecting the Report icon or by going to **File - Print Reports**.



Select the BHA Analysis and SAG tab and select what is to be included in the report. It is possible to create the report as PDF or Excel. If Excel is selected, the BHA Deflected Shape and Slope Charts option will no longer be available. Then select **File - Print**.

File Units Options Tools C

New Ctrl+N

Open Ctrl+O

Save Ctrl+S

Save As

Print Reports

Generate Reports

Generate Reports

File

Logo

Options

PDF Report

☒ Include company logo

☒ Include cover page

☒ Include header

☒ Include footer

Select All

Unselect All

Hydraulics Torque and Drag BHA Analysis and SAG Non-Mag Spacing Raw Surveys

☒ BHA Overview and Calculation Parameters

☒ BHA Trend and SAG Correction Data

☒ BHA Deflected Shape and Slope Charts