reduction effects from special torque-reducing drilling tools is a further important output of a TQ & Drag engineering package. Initial friction factors will be obtained from industry reports or by using well data from previously drilled wells. While drilling the well, friction factors are back-calculated, allowing realistic analysis and prediction for sections ahead and future wells in the area to come. By including hydraulic effects, the additional viscous forces and pressure induced stresses can be further included in this advanced analysis.

One of the most valued products of real-time drilling dynamics is the stuck-pipe calculator, which is used to predict a potential stuck point depth during the drilling process. Its analysis is based on measured surface torque, pipe twist, and surface over pull and stretch, taking into consideration hole inclination friction factors and borehole stability conditions. Modelling results are typically presented in traffic light display for ease of reaction to upcoming hazards.

Another important output of the TQ & Drag package is the critical rotary speed analysis. It predicts the rotational speeds at which resonant frequencies may develop. This analysis is taking into account axial, lateral and torsional vibration modes, and highlights rotary speeds to increase chances of avoiding and preventing excessive string damage and BHA failure during drilling.

Drilling hydraulics

The aim of a hydraulics optimization and analysis package is to model downhole circulating pressures during drilling, tripping and running casing in order to enhance bit hydraulic performance and ensure effective hole-cleaning as well as bit cutter cooling.

Basis for hydraulic engineering is the rheology model selection, a software-supported fluid builder device, which allows accurate definition of fluid properties for use in all subsequent hydraulic engineering calculations.

Properties of selected drilling fluids are typically stored in catalogues for re-use in other analysis models. A rheology modelling tool, for example, can analyse drilling fluids and automatically selects the most suitable rheology model based upon viscometer readings. Power Law, Bingham Plastic, Herschel Bulkley & Robertson Stiff models are supported by most hydraulic packages.

Swab/surge and equivalent circulating density (ECD) analysis are performed to reduce the risk of formation breakdown or swab-induced influxes during tripping operation and drilling. Drill string geometries and cuttings concentration in the mud column are equally considered in the ECD calculation for defining the operable mud window. Cuttings transport ratio and annular critical velocities are additional outputs of the model.
Most hydraulic software packages feature a fluid temperature modelling functionality, which provides a quasi-steady state temperature model, incorporating an advanced compositional density and HPHT rheology model. This allows to simulating a number of drilling scenarios, i.e. complex geothermal gradients, horizontal wells and dual-gradient mud systems. This functionality is, in particular, required for an accurate prediction of ECDs, and equivalent downhole mud density as well as rheology under high-pressure, high-temperature (HP/HT) conditions.

As an output, the hydraulic software package includes several modes of optimization, including pump pressure, flow rate, % bit pressure loss and bit total flow area (TFA) calculations. Bottom hole horsepower curves can be generated, showing hydraulic power and impact force with varying flow rate and bit TFA. Nozzle configuration and TFA can be calculated depending on flow rate and surface pressure conditions, thus enhancing and optimizing the bottom hole hydraulic energy for maximized rate of penetration (ROP). Other responses and feedback mechanisms from a hydraulic software package are the calculation of the maximum running speed for BHA's and casing strings (with both open and closed pipe) in order to avoid borehole damage due to surge and swab pressure effects.

For the selection of most efficient parameters, a sensitivity analysis allows the calculation of all pressure limits and tolerable ECDs at varying flow rates, indicating minimum and maximum flow rates.

Casing and tubing analysis
A modern casing design package allows the drilling engineer to design the minimum number of casing strings required to safely complete a well, thereby maximizing drilling efficiency and optimizing well capital cost (Fig. 4.2.14).

For each casing selection, the casing setting depths are automatically calculated in the casing analysis package based upon pressure data and user-defined constraints such as trip margin, kick tolerance and maximum open-hole distance.

The design procedure of a casing string and its strength analysis should include: 1) uni-axial, half bi-axial, full bi-axial and tri-axial stress checks for axial load cases; 2) bust and collapse load cases for all stages of the well's life cycle, including all drilling phases with their changing mud properties or pressure imbalances; the latter includes well-kicks or mud losses and the analysis of the well production phase after drilling under different temperature and pressure conditions; 3) graphical plots, tabular data and traffic light pass/fail indicators should allow rapid identification of problematic loading conditions.

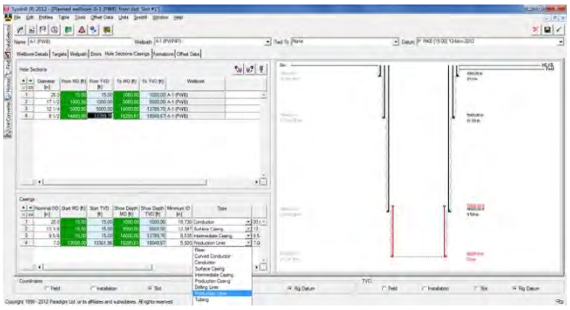

Fig. 4.2.14: Casing design and calculation template from Sysdrill well planning & engineering suite.

As casings do wear with time and with the deepening of the well due to the friction by the rotating drill string, a casing wear module should be applied to predict internal casing wear for a number of drilling operation and should be able to de-rate casing thickness for burst and collapse calculation accordingly. Alternatively, a calliper log can be incorporated as a percentage-wear identification measurement device and used to planning ahead the drilling process.

Cementing engineering
A cementing engineering and analysis module is used to plan cementing operations in order to ensure the safe slurry pumping schedule among casing strings and drilled hole, the annulus, or and cement plugs for directional drilling side tracks or plug and abandonment programs. It optimizes pumping operations for variable flow rate schedules, i.e., fixed flow rate, fixed bottom hole pressure, and free fall cement in order to safely manage down-hole pressures during such operations to avoid to fracture the