B. Calculation objectives and necessary tool characteristics

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Creating a finite element computational model includes several steps. The choice of the tool is essential and depends on several criteria.

B.1 According to the object to model

First, computational software must be adapted to the object one wants to model.

a) The complexities are different for bridges (standard short-span structures or complex structures with several spans), buildings, or geotechnical structures (retaining walls, tunnels, dams...).

Depending on the size of the object, one or more modeling scales can be defined:

- a **geological scale** (which aims to process a structure in its environment according to geological data),
- a **global scale** which aims to handle a structure as a whole (longitudinal calculations of bending for bridges for example),
- a **semi-local scale** with a more refined mesh for some elements of the structure (transverse calculations under the actions of axles for bridges, for example),
- a **local scale**, with very refined modeling and post-processing of the results (calculations of reinforced concrete for punching, diffusion or bracing reinforcement, for example).

b) An object can result in several models that complement each other.

Scale	GLOBAL	SEMI-LOCAL	LOCAL
Bridges	Longitudinal bending	Transverse bending	Stress concentrations (anchorage or deflection zone of cables, concentrated support)
Building	Load path / Bracing (wind, earthquake) / Dynamic calculation	Local bending of horizontal elements (floors, foundation slabs)	Concentrated, accidental loads (anchorage area, machine supports)
Geotechnics	Backfill, retaining wall	Faillure of anchored tendons, draining...	

c) In the case of a structure whose construction kinematics have an impact on the final state, the software must be able to authorize the complete simulation of the phasing, allowing, among other things, selective activation of the elements (such as the tensioning of prestressing cables and braces, for example), which makes it possible to work on the part of the structure under construction.

d) If a dynamic calculation is necessary (for example for a seismic calculation considering the effects of the soil or a vibration calculation or even a fast dynamic problem such as an explosion) not all software can be used.

e) Non-linear calculations are not systematically possible (calculation with material non-linearities, elasto-plastic supports, calculation of large second-order displacements for buckling verification, etc.).

f) Modelling of cable structures (whose transverse stiffness to bending and torsion is not very important compared to the longitudinal stiffness) is also particular and only provided by some software.

g) The determination of a thermal field (volume loading expressed from a variation in temperature and the coefficient of thermal expansion of the material) may require additional modules to the software.

h) Foundation modeling, for a foundation slab with uplifting, for instance, is generally linked to non-linear calculations and thus agrees with point d).

B.2 Depending on the study phase

The design phase of a structure has an impact on the level of precision expected from the calculations.

- In the Preliminary Study phase, the modeling must remain pragmatic, simple, and give approximated results.
- In the Preliminary Design or Project phase, a pre-dimensioning of the work must be established as a basis for a bid. The calculations are more thorough, even complex, but rarely exhaustive. Models must be fast, flexible, and easy to correct so that they do not restrict the project and allow for easy testing of variants.
- During the Execution phase, when the project is stopped, the calculations must be completed, they can be complex, and must give concrete and exploitable results to guarantee a dimensioning that is both safe and optimized.

The table below shows the level of detail generally expected for each phase. Depending on the specificities of the project and the requirements of the customer, the content of the phases may vary:

Object \ Advancement	Preliminary Study	Pre-design	PRO	EXE
	Ratios, Feedback, Simplified		Global model + semi-local	

Bridges, Industrial Building, Civil engineering structures	Ratios, Feedback, Simplified global model (a 2D model is preferred)	Global model	verifications or even verifications for critical points	Global model + semi-local + generalized local

B.3 Based on the verification objectives

For the same object and the same study phase, several models may have to be set up, each dealing with different verifications.

One must try to ensure that the same model can meet as many verifications as possible, but the problems often have to be decoupled.

B.4 Based on the expected results

The choices can be influenced by the results different software can handle.

a) Integrated post-processing modules make some software interesting, in particular those that allow the rebars of reinforced concrete sections to be obtained from stresses, or those that incorporate the verification of steel profiles when buckling or the verification of conventional connections. Beforehand, it is essential to check the conformity of the post-treatment with the reference regulations of the project.

b) The types of output results can vary and be relatively adaptable (listings, stress diagrams, maps, combination envelopes with or without conservation of concomitances).

B.5 Depending on time and resources

In terms of deadlines, and therefore budget, a distinction must be made between the modeling time (geometry, loads, combinations, etc.), the calculation time, the time to set-up (debugging errors, verifying support conditions, etc.), and finally the analysis time. These durations can vary significantly depending on the software because their user interface is less intuitive (the design interface can be either graphical or programmable in a command window or using spreadsheets). The extraction of results is not necessarily instantaneous and can be useful to identify critical points.

Moreover, the resources available within the design office guide the choice of the type of calculation: the hardware, on which the software is installed, must be open, so does the user license, so that it can be easily handed over to another user. The availability schedule of the tools can play an important role in deadlines and possibly lead to a change of software.

If the design office has a type of hardware with reduced capacity, the degree of complexity of the calculations is reduced accordingly. And if the complicated computational model is kept, the design office should not "tinker" a model adapted to the capacity of its equipment, because the simplifications adopted can then lead to issues concerning the accuracy of the results. It is then in the design office's best interest to subcontract the calculation.

For large structures, it may be preferable to implement two levels of modeling, using sub-models. Indeed, a single model can quickly become disproportional in size, and therefore difficult to structure and manipulate. However, it is necessary to be able to link the models together. Furthermore, the need for specific computing capabilities can also lead to the splitting of models and the use of different software.

Another reason for splitting the models as described above can be linked to the study schedule (a consequence of the organization of the projects): the calculation of the whole work sometimes precedes by several months, for important projects, the calculation of certain parts of the work. There are no reasons not to compensate by post-processing for certain shortcomings of the software, by extracting the results of a sub-model and to process them manually or using another software.

⚠ An equally important resource is the staff, i.e. the engineer in charge of modeling. They must be trained to use the software. If the engineer is new to the software, the learning curve should not be underestimated, as the time required to design and develop the model can be greatly increased. Tutoring with a senior engineer is strongly recommended, despite the time investment involved.

B.6 Depending on how user friendly the interface is

Finally, making the software user friendly is essential.

a) A software with a complete manual (installation, handling, and operating instructions) is always much appreciated. The presence of a catalog of examples and applications, tutorials, and manipulations are extras but also valued.

b) The possibility of programming (creating and reading a text code in a programming language of one's own) allowing intuitive and fast data entry is an asset. It can offer many possibilities to the user, for example, to automate the modeling of simple and repetitive model structures or to adjust the layout of the results, by providing text or Excel outputs adapted to the studied sub-structure.

c) Confidence in the software saves a significant amount of time by avoiding superfluous verifications. Thus, having regular updates is an indicator, as is the existence of an available and reactive technical hotline, capable of providing punctual assistance on a specific model. Of course, trust does not dispense the model verifications explained in this guide.

d) The version of the software can also play a role, in the case where certain features have been added/removed or where the stability and/or speed of a version is not satisfactory.

e) Some software have complete libraries (materials, profiles, bolts, assemblies...) that save a considerable amount of time. Functionalities specific to civil engineering projects also exist, such as the application of regulatory automatic loads (types A(l), Bc, LM1, LM2...).

f) Depending on the standards that apply to the project, the software can propose loads, combinations, and pre-programmed verifications. This is a helpful feature but it must always be checked using simple cases.

g) A render function is an advantage because it allows visual verification of the type and orientation of the profiles or bars. Besides, some software allow a 3D export which is a very useful communication support in meetings with stakeholders (see also chapter E.3 for the BIM part).

h) A software that specifies the line of the data file that contains an error or the list of wrongly modeled objects (overlays, ...) in the spatial model offers a real advantage. Error messages must be clear and precise (if possible, in the numerical language of the engineer).

Experience feedback:

Feedback is important: meetings or feedback documents should allow drawing positive and negative lessons from ongoing or completed projects. They must cover the methods used, but also the IT equipment used or even the production level that was reached.

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