The elastic behaviour of Ekstroemisen grounding zone

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Introduction - elastic beam approach

The influence of ocean tides on an ice shelf was first described by Robin (1958). He observed the vertical movement of the Maudheimisen (today: Quarisen) during the Norwegian-British-Swedish Antarctic expedition from 1949 to 1952. A simplified model for the description of the tidal influenced behaviour of ice shelves was introduced in Glaciology through Holdsworth (1969, 1977). His approach was based on the work from Hetényi (1946). This standard elastic beam approach deals with small displacements of a thin elastic beam (s. fig. 1). The acting forces are caused from ocean tides. The input data for this model are mean ice thickness h, tidal signal for one site w_a and the assumption of a fixed grounding line (hinge line). A detailed application of this approach is published in Holdsworth (1974) for Erebus glacier tongue.

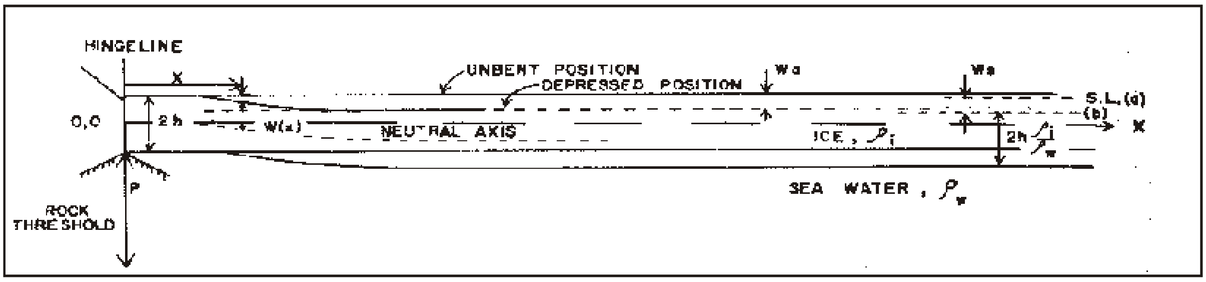

Figure 1: Holdsworth model (1969) for a glacier tongue derived from Hetényi (1946)

The bending for every position w(x) can be formulated as:

$$w(x) = w_a \left[(1 - e^{-\beta x}(cos\beta x + sin\beta x) \right]$$

$$\beta^4 = \frac{3}{8}\rho_w g \frac{1-\nu^2}{Eh^3}.$$

with:

E	Young's modulus
β	damping factor
υ	Poisson's ratio
ρ_w	density of water
g	gravity acceleration.

Vaughan (1995) compiled different studies with results for Young's modulus. The published bandwidth showed values from 1 to 10 GPa. He examined further the relation between β and the effective ice thickness and reanalyzed these studies with the result of a mean Young's modulus of 0.88 GPa.

Improved mechanical model

Field observations have shown that the influence of ocean tides do not end at the grounding line, rather vertical movement can be observed 2km behind the grounding line on grounded ice (Vaughan 1994, Riedel et al. 1999). Therefore it is necessary to develop a model that can describe the complete elastic behaviour of ice shelves caused from the ocean tides. The objectives for the development of such a model being the incorporation of all geometrical information to describe the object, to get a best fit between observed and modelled deflections and to derive a value for the Young's modulus without an assumption for an effective ice thickness.

A two dimensional finite-element model (s. fig. 2) was developed with a description for the ice body through iso-parametric four sided elements with a mesh width of 220m*500m (Riedel 2002). As input data for the finite element mesh, served discrete values for the ice thickness and the surface topography from field observations (s. fig. 4). The vector of forces is replaced through the vector of displacements (the observed tidal signals, s. fig. 5). The boundary conditions are a fixed model rim at the limit of tidal influence on grounded ice (A1 in figure 2), a kind of till layer that allows ice - bedrock interaction in form of a flexible zone with a different feather stiffness in relation to the feather stiffness for the ice shelf swimming on the ocean.

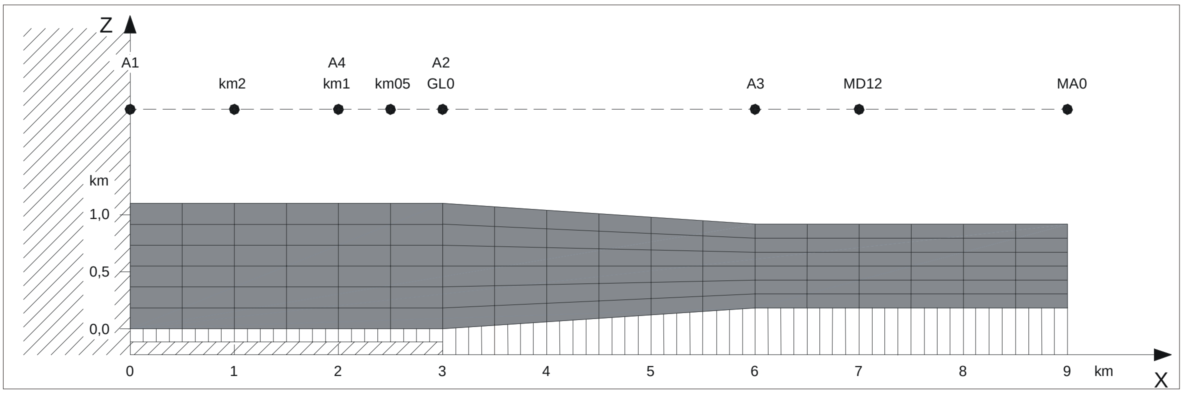

Figure 2: Two dimensional finite element model for Ekstroemisen grounding zone.

For the different model runs only a subset of the vertical displacements of the different sites was used, i.e. the vector of displacements consisted of the tidal signal for one site on grounded ice and one position on the ice shelf. The displacements for the other sites were calculated and compared with the observations. To get a best fit between model and observation the value for the Young's modulus was adapted.

Results - model comparison with field data

During the Polarstern expedition ANT XIV/3 in the austral summer 1997 a combined geophysical and geodetic field program was carried out in the vicinity of the Ekstroemisen grounding line. The work was done in close collaboration with the AWI geophysics and is published in Nixdorf et al. (1998a, 1998b), Riedel and Vogel (1998). The position of the grounding line was well known from former expeditions and investigations (Karsten and Ritter 1990, Mayer 1996). An overview of the investigated area and the distribution of observation and model sites is given in figure 3.

The main objectives of this field study were to determine exactly the position of the grounding line, to derive the geometry of the ice body out of terrestrial, seismic and GPS observations. A further objective was the study of the influence and the range of ocean tides onto the ice body with continuous observation methods, like GPS, gravity and tiltmeter surveys.

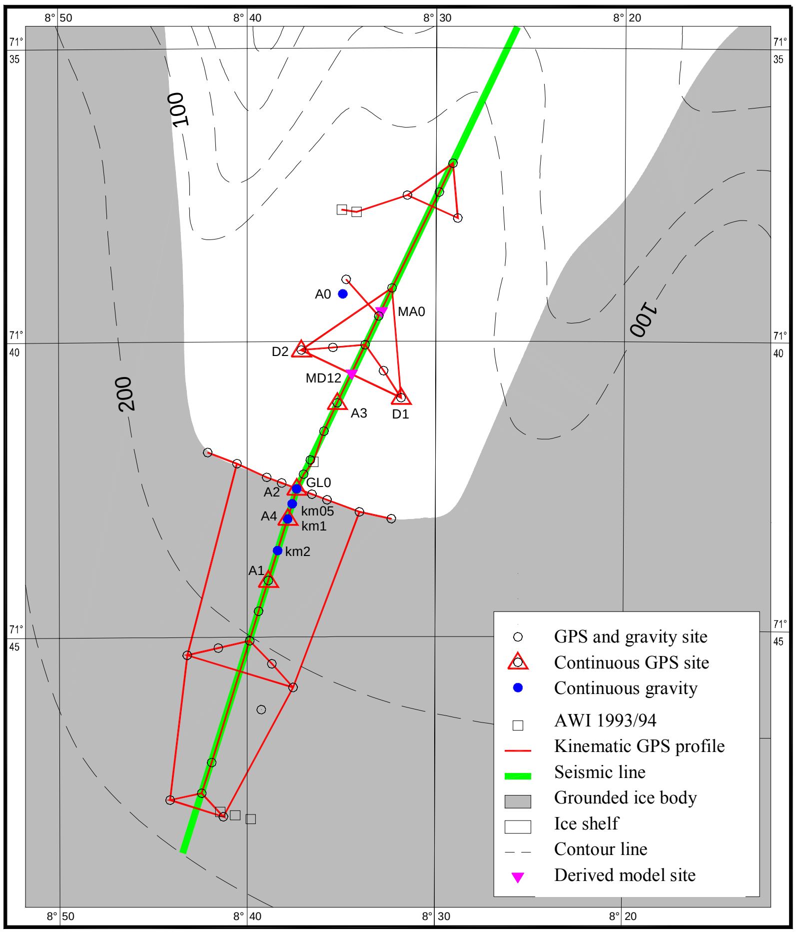

Figure 3: Map of Ekstroemisen grounding zone with observation sites.

The geometrical observations served as input data for the two dimensional finite element model. The combined three dimensional ice surface topography with the georeferenced ice thickness model describes exactly the geometry of the ice body. A vertical cross section through this model, see figure 4, served as the geometrical model for the finite element mesh.

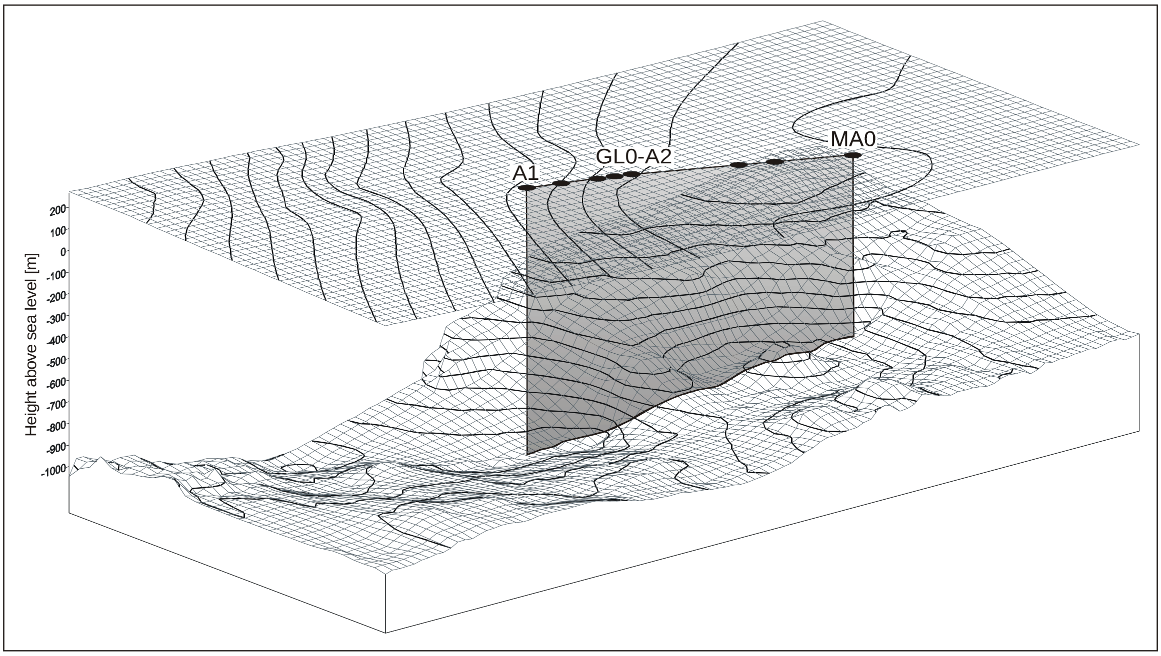

Figure 4: Three dimensional geometrical model for the surface topography and the ice thickness for the Ekstroemisen grounding zone. The grey vertical cross section describes the geometrical input data set for the finite element mesh.

The build up of the vertical displacement vector for the mechanical model was difficult, because the observations in the field were not recorded simultaneously on all sites and the data sets for the time series analyses were short and interrupted (Riedel and Heinert 1998, Riedel et al. 1999). Therefore not the original observations were used, but the signals of synthetic waves were introduced in the model calculations (Riedel 2002). These synthetic waves were composed from Fast Fourier Transformations and optimised amplitude estimations, see figure 5, which shows the range of ocean tides on grounded ice over a distance of 2km. The semi diurnal amplitudes (S2,M2) of the synthetic waves reach values up to 7mm for the position km2.

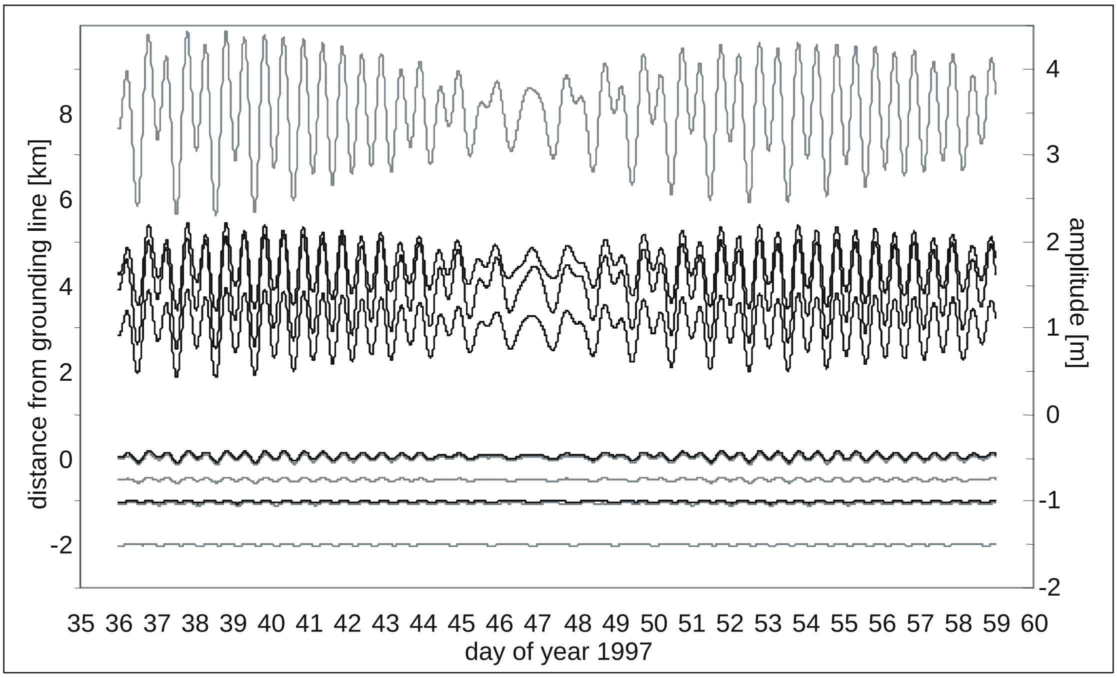

Figure 5: The synthetic signals for the different observation sites, derived from short time tidal analyses.

If the standard elastic beam approach is compared with the two dimensional finite element model, one will get as a result for the Young's modulus 0.9 GPa instead of 2.7 GPa with the elastic beam approach for the Ekstroemisen grounding zone.

A further comparison between the synthetic signals and modelled signals shows at the different sites, which were not included in the displacement vector that this new mechanical model describes very well the tidal deflection for the grounded ice body. The differences for the vertical displacement between the finite element model and the observations are less than 6mm.

The differences in the vertical deflections at the different sites for the ice shelf area are less than 4.5 cm for the finite element approach and less than 6cm for the bending of the elastic beam approach.

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