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MONITORING OF PHYSICAL-MECHANICAL STATE OF THE SEA ICE

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ABSTRACT

Information about physical and mechanical processes in the ice based on instrumental observations on the drifting and land fast ice is presented. Methods of measurement of the parameters of ice oscillations and waves in Russian expeditions in the Arctic were used. Force of interaction of sea ice generates large-scale effects of self-excited oscillations. Natural dynamical processes in the drifting ice floes (system "ice-ice") reflect many forms of deformation and failure of the ice, observed at the interaction in the system "ice-structure". Especially it relates to the effects discussed in ISO 19906 2010 as a lock-in or self-excited vibration. The mechanics of interaction of a sea ice with icebergs also can be considered as analogue of interaction in the system "ice-structure".

INTRODUCTION

Sea ice cover is a dynamical dissipative system of the geophysical level in which physical-mechanical processes of different scale and intensity occur simultaneously. Study of physical-mechanical properties of sea ice cover is based of consideration of ice as a material, construction and as a geophysical discrete medium which is under impact of atmosphere and ocean. Periodic horizontal shears on significant space of ice are registries; they are related to the class of self-excited oscillations. The mechanical processes in dynamic system "ice-ice" are very similar to processes in system "ice-structure". Intermittent crushing of the contacts of ice floes, with regimes of resonance events, chaotic vibrations and impacts in ISO 19906 2010 are revealed

It follows, that a necessity of a complex investigation of the sea ice for solution of weather and climate tasks and ice technology interconnected with ice impact to offshore engineering structures. Scientific and applied problems of the sea ice are interconnected and are solved by experimental and theoretical methods. A structure of the sea ice cover is analyzed by using of theories of elasticity, viscosity and plasticity.

Thus general strategy of investigation was realized at natural experiments and monitoring of the mechanical state of land fast and drifting ice in the Arctic. As a rule excepting traditional measurements two main tasks were set (Ashik et al. 2011):

- investigation of physical-mechanical processes of deformation and failure of ice to obtain data for development of forecast method of ice state and its failure in advance of several hours;
- consideration of possibility in the future use of obtained data for solution of tasks of ice bearing capacity and evaluation ice actions onto shores, bottom and structures of the Arctic shelf.

The technology of monitoring of ice state are based on interconnected tasks of ice mechanics, morphometry and geophysical processes, which occur under action of external forces from atmosphere and water. The inverse tasks allow using mechanical changes in ice and giving estimate of forces which cause these changes. It makes a possibility of prediction of time and place of extreme ice phenomena, which is especially important during exploitation of the offshore structures and navigation in ice. Such approach allows to integrating applied and scientific tasks: evaluation of ice strength of local and meso scale, short-term forecast of sea ice compression, evaluation of ice loads on structures…

METHODS OF INVESTIGATION

Investigations of large-scale mechanics of ice on base of measurements with involvement of satellite ice images are carried out. A monitoring of ice includes strain meters and stress meters in ice, seismometers, tiltmeters, GPS-receivers (Smirnov, 1998). The technology of evaluation of parameters of large-scale mechanics of the sea ice consists in arrangement devices on landfast and drifting ice and obtaining of initial data for processing and using corresponding programs.

In this paper characteristics of deformation and failure of the ice field obtained by indirect indication using tiltmeters and triaxial seismometers are considered. Tiltmeters CH-2 of pendulum type with sensibility to tilts 1mV/μradians and molecular-electronic seismometers CME-4111-LT were used. Sensitivity of a seismometer - 4 kV/(m/s) in a range of frequencies of 0.02-60.0 Hz. Seismometers were installed on the ice and registered velocity of displacement of three components: X,Y are horizontal, Z is vertical. A continuous series of digital observation data with discreteness 100 Hz was obtained. Sensitive elements of the seismometer react to acceleration. The acceleration signal then with correcting electronics (integration of the signal inside the device) produces output amplitude-frequency characteristic of velocity of displacement an ice. Thus, the signal at the output of the seismometer has mm/s dimension. Seismometers and tiltmeters showed high reliability of work at low temperatures - 30° C. The monitoring on ice cover with the size up to tens km and thickness up to 2-3m are carried out.

RESULTS AND DISSCUSSION

Examples illustrating main features of physics of oscillation and wave processes at different ice conditions in the areas of observation are presented.

Flexural-gravity waves in ice. Low-frequency oscillations caused by thermal crack formation, during compression and ridging, at sharp wind rushes practically uninterruptedly in the ice floes had registered. Flexural-gravity waves in the landfast ice are the main information about ice state (Wadhams, 2000). According to Figure 1 cracks were accompanied flexural-gravity waves by duration for 7 seconds. These periodic impulses arose because of passage in landfast ice waves of a swell with the period 15-25 sec. Stress in an ice from a bend thus could reach 0.1MПa (Smirnov et al. 2011).

From theory and experimental investigations of parameters of phase and group speeds of flexural-gravity waves we can define following ice characteristics: modulus of elasticity, ice thickness. An increase of intensity of flexural-gravity waves can be a base for development of short-range forecast of fast ice failure.

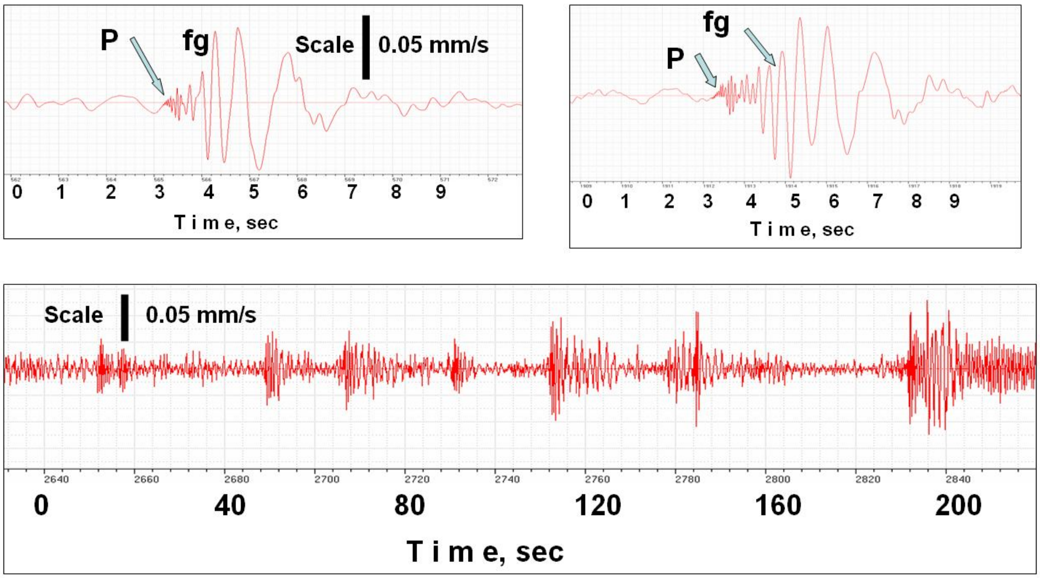


Figure 1. Fragments of records of flexural-gravity waves (fg) in ice – top) and intermittent pulses at formation of cracks – bottom). P - longitudinal wave. The thickness of the landfast ice is 1.2 m. Laptev Sea, 2012.

Intermittent impulses during ice compression. In the ice cover, periodic shear of the self-excited oscillations class is registered (Figure 2). It is a stick-slip process at the compression and shear on a crack in the fast ice. The maximum double amplitude at displacement reached one mm.

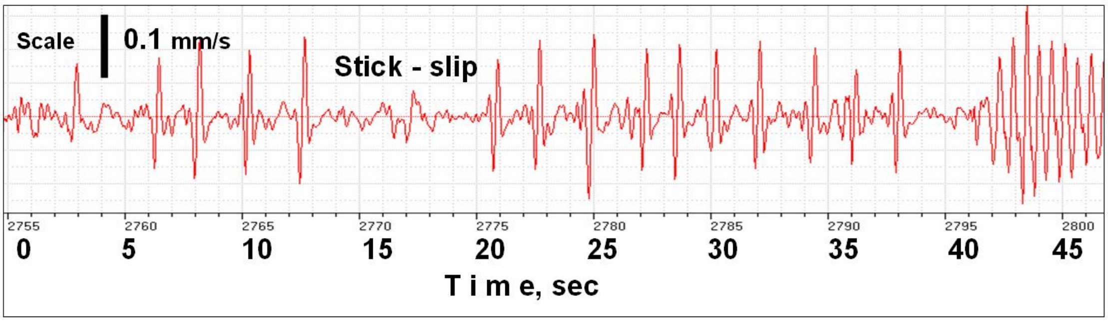
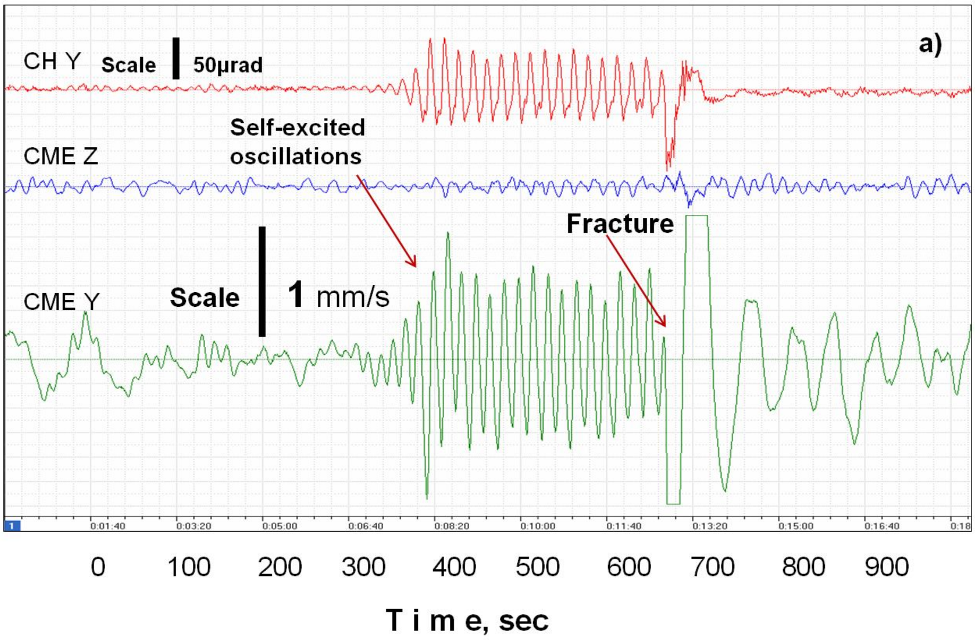


Figure 2. Fragments of records of cyclic ice shear (stick-slip) at compression, periodicity of the impulses make up 0.5-2 sec. The thickness of the fast ice is 1.2 m. Laptev Sea, 2012.

On the drifting station NP-38 a self-excited process before the fracture of the ice field (Fig. 3) is registered using seismometers and tiltmeters. Tiltmeter CH Y and seismometer CME Y registered oscillations with a period of 17 seconds. The vertical component of the seismometer CME Z practically did not respond at these oscillations. The self-excited oscillations were finished by a sharp pulse (drop of stresses), which denotes fracture with shear.



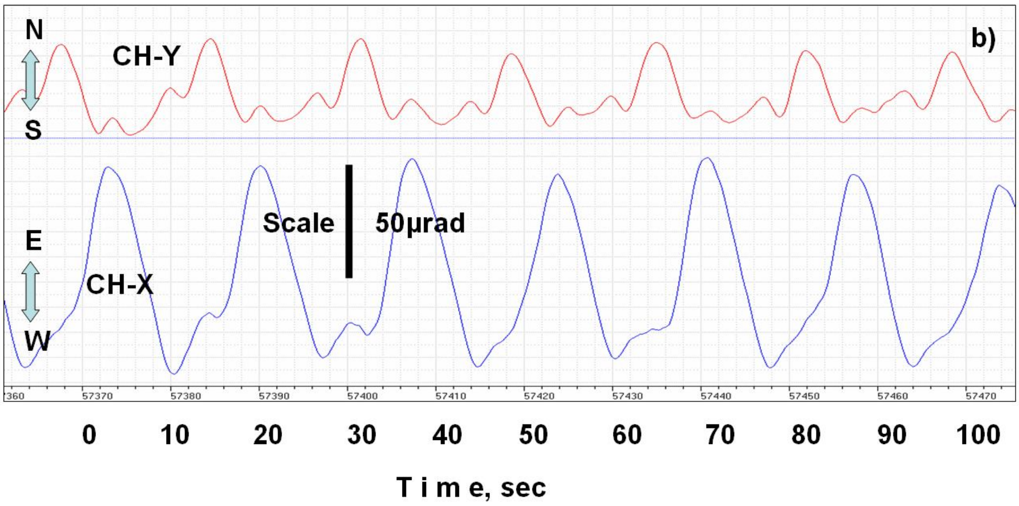


Figure 3. Records from devices on drifting to an ice in one point: CH Y-from tiltmeters, CME Z - from vertical components, CME Y - from horizontal components of a seismometer. Examples of arising of self-excited oscillation before the fracture of the drifting ice field - a); fragment of record of a sawtooth form from 2 tiltmeters - b). The ice thickness is 2 m, camp "North Pole" (NP-38, 18 March 2012).

For generation of such self-oscillations (self-excited vibration) in the ice the periodic forces are not required. The source of energy is compression force caused by a temperature gradient, wind and surface currents. Forces of friction and cohesion in ice serve as the mechanism of damping. Interaction process is characterized by regular repetition of accumulation and drop of stresses reflecting relaxation properties of ice in the scale of observations. Excitation of mechanics oscillations, period and amplitude of which do not depend on character of the external impact is caused by own properties of the ice with crack. Duration and intensity of self-excited shear with friction characterize ice rheology, its failure mechanics, forming a structure of emitted waves. Duration of self-excited processes reaches tens of minutes. Transition from stick- slip to near sinusoidal oscillations depends on relative speed of displacement on the walls of the crack. Self-excited oscillations are used for forecast sign of the ice compression and ridging and can be used to develop technology of estimation of compression force and forecast fracture.

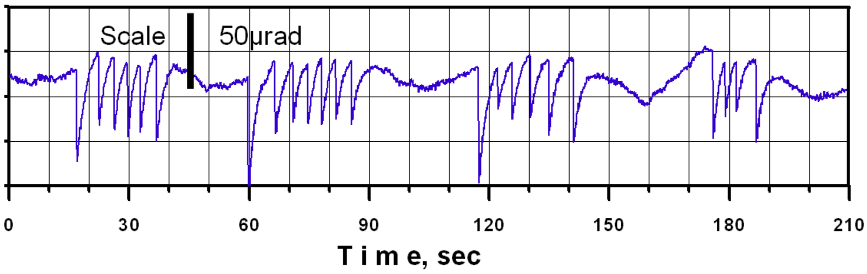


Figure 4. Fragment of record from tiltmeter on the iceberg in sea ice. Interaction of iceberg and sea ice is noted. Sawtooth series of pulses connected with own oscillations iceberg (bobbing and rocking) (Smirnov et al. 2010).

Interaction of the iceberg with drifting sea ice is accompanied by large-scale events of stick-slip (Figure 4). A tiltmeter was established on iceberg. The periodic oscillations with a period of T = 45-55 seconds were detected. One can see sawtooth series of pulses related with iceberg own oscillations. The series of iceberg tilts/accelerations consist of 5-7 pulses. The initial impulse tilts\accelerations is always greater than following ones. Taking into account the iceberg mass global dynamic forces of interaction with sea ice reached 18 MN.

Monitoring of physical-mechanical state of the sea ice. One of typical examples of ice monitoring on the station "North Pole" (NP-38) is shown in Figure 5. The processes of compression of ice were caused by passing of a cyclone. In this case, flexural-gravity waves, self-excited processes, shears and fractures were fixed.

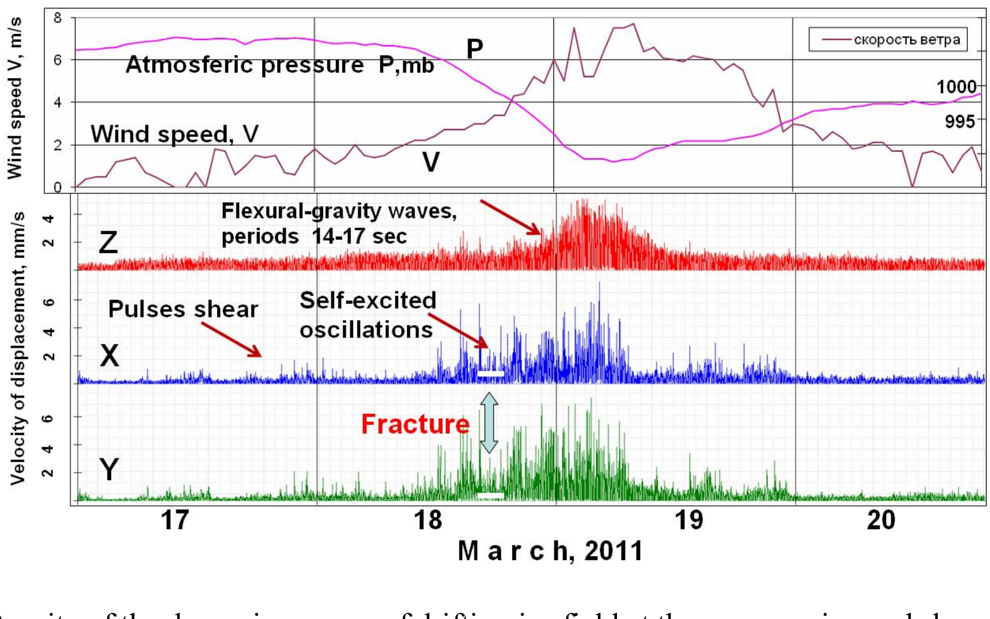


Figure 5. Intensity of the dynamic process of drifting ice field at the compression and shear in the region of NP-38 in the period of cyclone passing on 18–19 March 2011. Z is vertical velocity of displacements of ice in range of flexural-gravity waves, X, Y are horizontal impulses at the compression and shear of ice; figured arrow - time of appearance of fracture of the ice field; meteor: wind speed, atmosphere pressure.

Before ice fracture, horizontal pulses of displacement of the ice field were registered: duration of entry was several seconds, total duration was up to 20 seconds. Periodicity of appearance of pulses reaches several minutes. As a rule, pulse of shear finishes by a mechanical process with a stabile period of oscillations.

The most important for understanding of the fracture mechanics was data with records of a sawtooth character when correlation of time of grow and fall of oscillation amplitude reached 1.5 (Figure 3b). Such processes at the periodicity of cycles of displacement or acceleration are related to non-linear oscillations. In compliance with Figure 5, a temporal period of appearance of self-excited oscillations and horizontal accelerations caused formation of cracks in the ice field of the station NP-38. The period and amplitude of self-excited oscillations depend not only on external impact, but and from properties of the system of "ice-ice". Duration and intensity of the self-excited shear with friction on rupture in ice characterize large-scale mechanics of ice failure accompanied by waves. Periodic pulsations of the ice floes can turn into quasi-harmonic oscillations which are a process of stabile slip with friction on the rupture. Duration of self-excited processes reaches tens of minutes and in the spectrum low-frequency peaks are remained persistently. Propagated from the ice epicenter elastic waves in the range of frequencies 0.2–1.5 Hz are one of the main indexes of occurring process of compression and formation of ice cover structure (Smirnov et al. 2011).

Before and after the compression and fracture of ice cover, satellite image of ice in the region of the drift was used. In a pattern of structure of ice, according to the Figure 6, size of side of mesa scale "rhombs" was from 100 to 200 km.

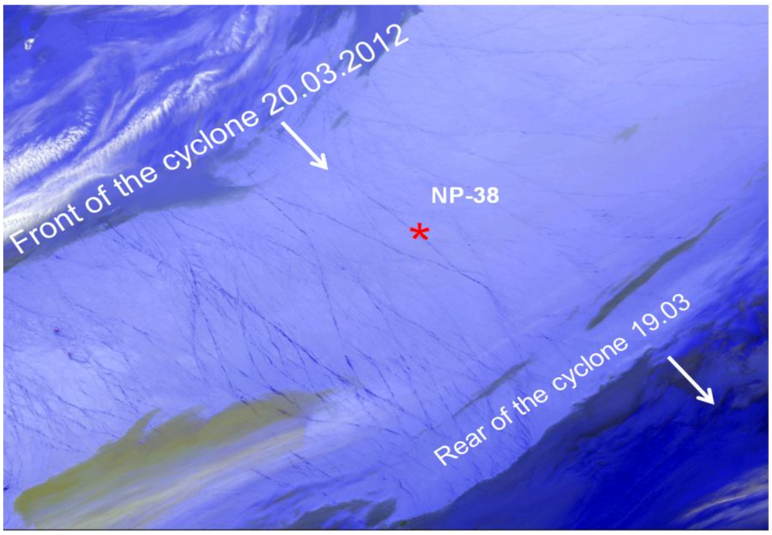


Figure 6. Patterns of structure in ice cover in the region of station NP-38 in the period of passing of a cyclone on 19 March 2011. Image of NOAA. Scale corresponds 1000 x 700 km

Fracture operates under higher loading rates [Schulson, 2004] and leads to brittle behavior, manifested by cracks, pressure ridges and rubble fields, and quite remarkably by strike-slip type oriented linear kinematic features that can run hundreds to thousands of kilometers through the cover [Marko and Thomson, 1977; Kwok, 2001].

Presence of developed structures crossing rectilinear canals and leads indicate a probability of formation relatively fast deformations on large areas of the ocean surface. Extensive ice rhomb features have angles of intersection of breakages in compared narrow range of 30–40°. The discussed

phenomenon is one of main factors for approach to explanation of nature of formation of polygonal structure of the ice cover.
After event of compression and a break of ice fields in area of camp of NP-38 were formed extended shear cracks with the formation of a chain of leads (Figure 7).

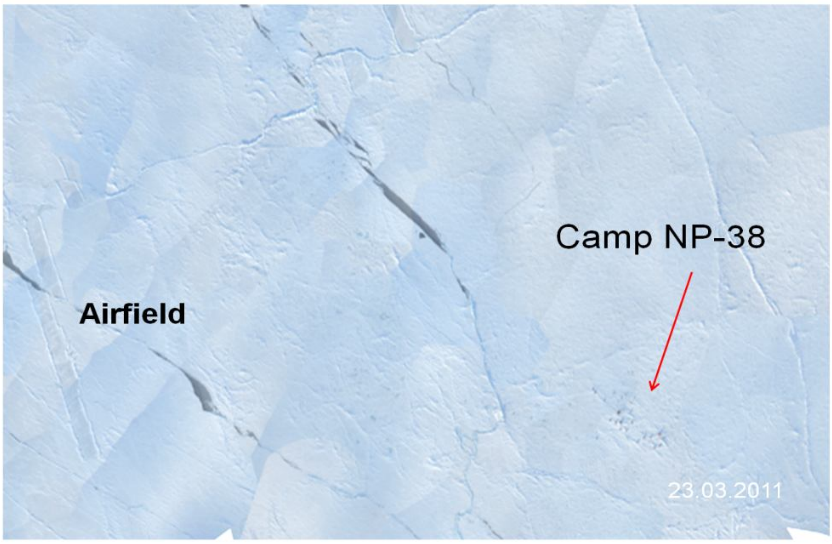


Figure 7. Aerial photo from pilotless aircraft

Large scale ice strength can be significantly decreased compared with laboratory ice test. It well confirmed by study of mechanics of ice failure and evaluation of ice loads on wide shelf structures or islands: with an increase of sizes of contact area of the system ice-structure a realized strength of ice is on two-three orders of magnitude less than strength at ice samples tests. A character of dynamic interaction of ice features both between them and with a structure has generalities. In this case, a similarity of deformation and failures forms of ice is occurred: at small relative velocities of relative movement ice behaves as a plastic body, at large velocities as a brittle. In accordance with it static and dynamic loads arise.

CONCLUSIONS

- Based on instrumental observations of physical-mechanical state of the ice field long temporal series of parameters of reaction of the ice field on events of compression, oscillation processes and fracture are obtained. Meteorological parameters, satellite image and pilotless vehicle images of the observation region are used for the analysis. It is shown that ice flexural-gravity waves arise from storm wind.
- New data about anticipatory phenomenon of intermittent impulses of shears of ice before an event of compression and fracture allow approaching to development of short-term method of forecast of compression and ridging of ice.
- Observations of physical and mechanical processes in the ice cover open large possibilities for obtaining new results in improvement of models of ice drift, monitoring of surface and internal waves of ocean, forecasting of ice compression, detection of extensive fractures which are important factors during solution of climate and of engineering problems.

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