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THE SEARCH FOR AND REGISTRATION OF SUPERWEAK ANGULAR GROUND MOTIONS

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Поиск и регистрация сверхслабых угловых колебаний поверхности Земли

Угловые колебания поверхности Земли сейсмического, индустриального и собственно земного происхождения зарегистрированы высокоточным инклинометром нового концептуального дизайна. Впервые зарегистрирована угловая компонента микросейсмических колебаний (микросейсмический пик).

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The Search for and Registration of Superweak Angular Ground Motions

The Earth's surface angular oscillations of the seismic, industrial and terrestrial origins have been registered with the high-resolution inclinometer of a new design concept. The microseismic peak was first recognized in the ground microradian motion.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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INTRODUCTION

In many research activity fields an essential factor for reliable data obtaining is the seismoisolation of sensitive elements of experimental equipment.

There are some — not rare — cases when the seismic activity detection by so-called inertial seismograph and compensation are on-line realized which allows one to reduce the vertical component of the Earth's seismic activity [1–4].

There are also circumstances where besides the vertical component compensation one needs to compensate also the *angular components* of the Earth's seismic activity.

As an essential example one takes the modern colliders: to keep maximal stable luminosity the variations in the beams space direction in collision area are to be minimized; one of the reasons of beams miss is their roaming due to the Earth's seismic motions.

In [5] a high sensitivity seismograph of the conceptually new design for precision registration of ground angular motion was proposed and realized. Further development of this method and some examples of the seismic phenomena observed are presented here together with an attempt to evaluate these phenomena affecting the extended physical equipment stable work.

1. EXPERIMENTAL SET-UP

The experimental set-up used (Fig. 1) represents a slightly modified prototype [5].

On the platform O_1 are positioned the laser L and quadrant photoreceiver QPr; on the O_2 platform are positioned the main sensitive element S and the calibration system C. In the experiment was used the semiconducting laser SP180 [6] with the focusing collimator device CF; the QPr used was QP100-G-SM [7].

The key component of the set-up is the *sensitive element* S containing the cuvette with liquid of high enough viscosity (an oil).

The laser ray is directed by semitransparent mirror SM onto the liquid surface and after being reflected is moved to the quadrant photoreceiver QPr where it is registered.

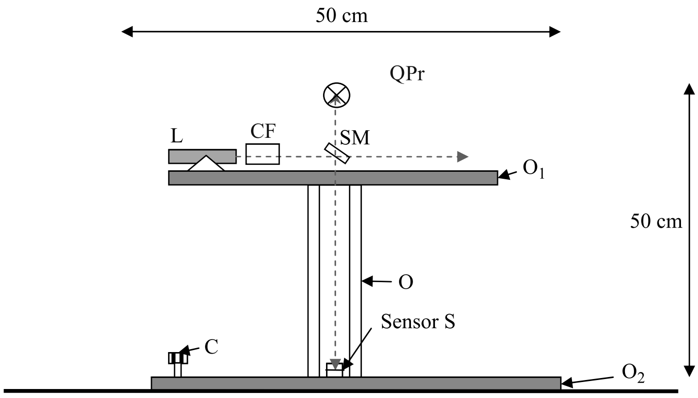

Fig. 1. The principal scheme of the Earth's surface inclination detector

The collimator CF focused the laser ray on the surface of quadrant photoreceiver QPr, which increased the set-up sensitivity to the Earth's surface inclination angle measurements; the focused laser ray diameter was 200 μm.

Due to horizontality of the reflecting liquid surface, the Earth's surface inclination changes the reflected laser ray direction, which is registered as laser spot displacement on the quadrant photoreceiver QPr.

With the help of precision calibration screw C the whole set-up was inclined at a fixed angle Θ. This operation determines the calibration coefficient K connecting the inclination angle Θ with the QPr response signal ΔU:

$$\Theta = K \triangle U, \qquad (1)$$

which allowed for measured data to be presented in angular units (radian).

To increase the set-up sensitivity the modified sensitive element was used. In the previously operated set-up [5] the main noise factor was the shaking of the liquid surface caused by high-frequency ground vibration. For this noise reduction, in this work a relatively small liquid depth was used. This depth was determined experimentally from the condition that the time duration of liquid surface horizontality recovering (after calibration displacement) should not exceed 1 s. The experimentally determined condition for oil was $D/h \leqslant 30$, with D as cuvette diameter and h as liquid layer depth. The use of small-depth liquid layer in the sensitive element avoids the surface wave appearance and results in the increase of precision of inclination angle measurements in the low frequency interval of 10^{-4}–1 Hz. The quoted frequency interval is an interval adequate to the thermostabilisation supported in the inclinometer surrounding media. The achieved inclinometer angular precision is $5 \cdot 10^{-9}$ rad.

2. THE INCLINOMETER TESTS

2.1. The Angular Component of the Earthquake. To test the high-resolution angular detector possibility, some measurements were made close to Geneva for the period of February–March 2011.

In the observation point there have been registered three significant far located earthquakes of $\geqslant 6$ units (Richter scale) and also a few earthquakes of 4–5 Richter units in the close vicinity (less than 600 km) to our set-up.

Figure 2 is the record (in Geneva) of the ground inclination angle caused by the earthquake in Siberia on 26 February 2011; an average amplitude of the quake in Siberia was 6.5 units. The quoted data are taken from seismic Monitor [6].

With the known Siberian quake coordinates, the distance to Geneva (on the Earth's surface) was determined: $L = 6160$ km. Taking into account $V = 3.5$ km/s speed of surface seismic waves propagation, one determines the delay time T_d in "Siberian signal" appearance on our set-up. Taking into account that Geneva local time differs by 1 hour from the world calculated time and also the delay time of the Siberian signal appearance in Geneva $T_d = L/V = 29$ min, one obtains the time of the earthquake begining $T_{\text{calc}} = 6$ h 21 min in Siberia (world time). It practically coincides with the published $T_{\text{pub}} = 6$ h 17 min (world time) [6].

Figure 3 shows in detail the central part AB of the above distribution; one needs to mention the presence of oscillations with 2 μrad amplitude and about $T = 12$ s period for the interval $\approx$ 5th–6th min.

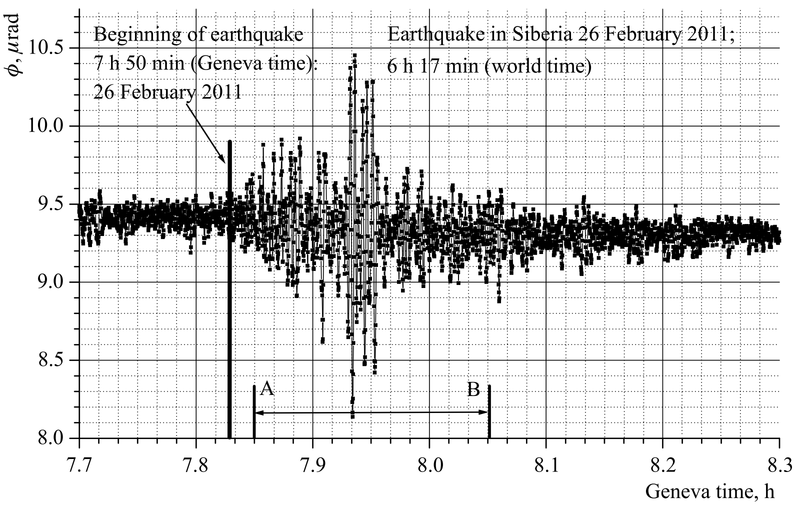

Fig. 2. An Earth's surface inclination angle ϕ (μrad) caused by the earthquake in Siberia, registered on 26 February 2011 in Geneva

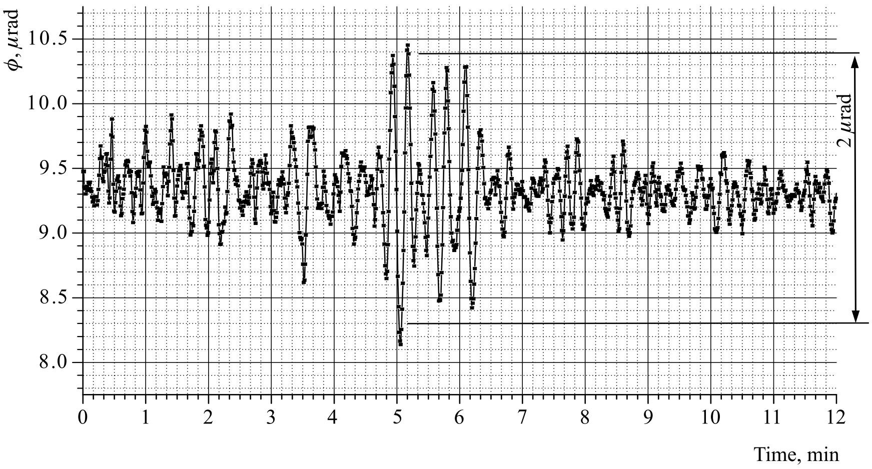

Fig. 3. The central part of the seismogram given in Fig. 2

*The quoted data are the first directly detected angular component of the Earth's surface seismooscillations**.

2.2. Earth's Surface Single Oscillation. Another illustration of the high sensitivity achieved with the new angular detector is the observation of the Earth's surface "single inclination" effect, shown in Fig. 4. This is a few microradians single event looking as the deviation from some fixed level and of a few minutes duration.

The origin of this "single inclination" effect needs to be studied.

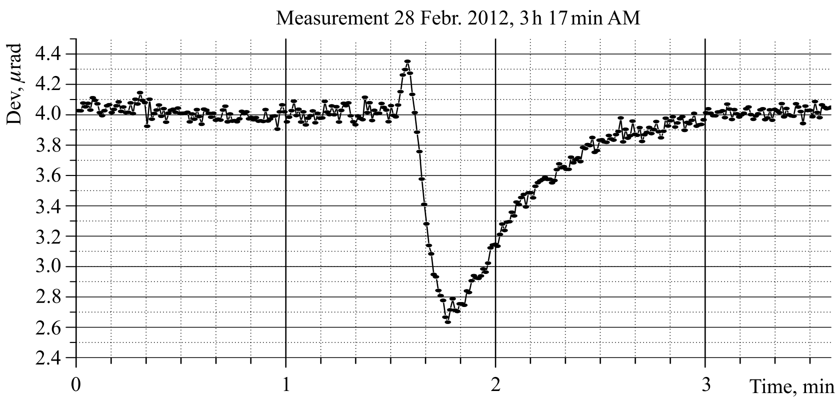

Fig. 4. The Earth's surface single angular deviation Dev (μrad)

*In the available literature this effect was not described.

2.3. Earth's Surface Oscillations of an Industrial Noise Origin. The further studies of the Earth's behavior with high-resolution inclinometer allowed one to conclude that the day time angular oscillations intensity is significantly higher than that at the night observation.

It seems that the possible reason is the presence of industrial-origin noise: high activity of the traffic, works in the neighboring (with our set-up) Lab room, people movement close to detecting set-up, etc.

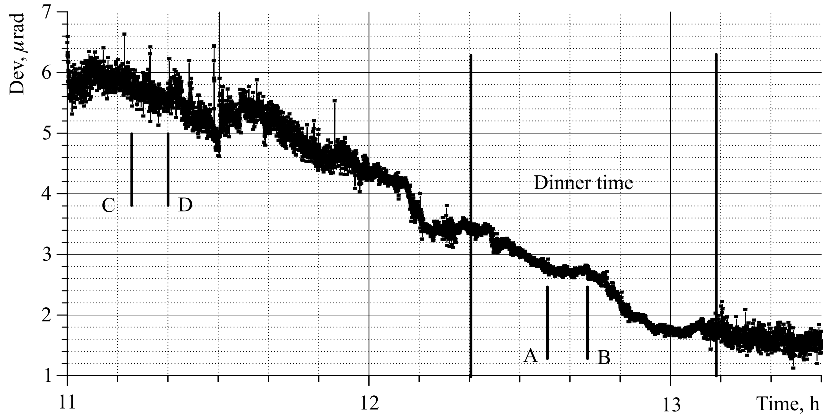

Fig. 5. Earth's surface angular oscillations Dev (μrad) of an industrial origin: comparison of the working hours and dinner time data

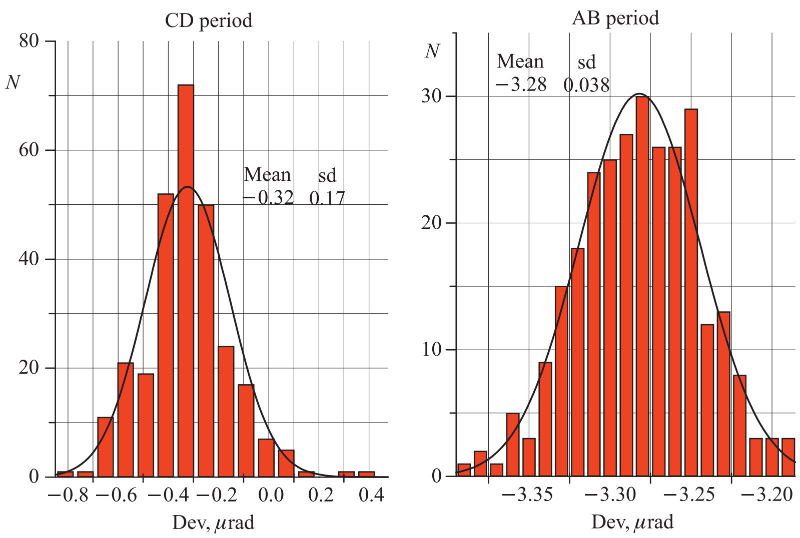

Fig. 6. Angular oscillations Dev (μrad) data plotted for the CD and AB periods; the data of Fig. 5 are used

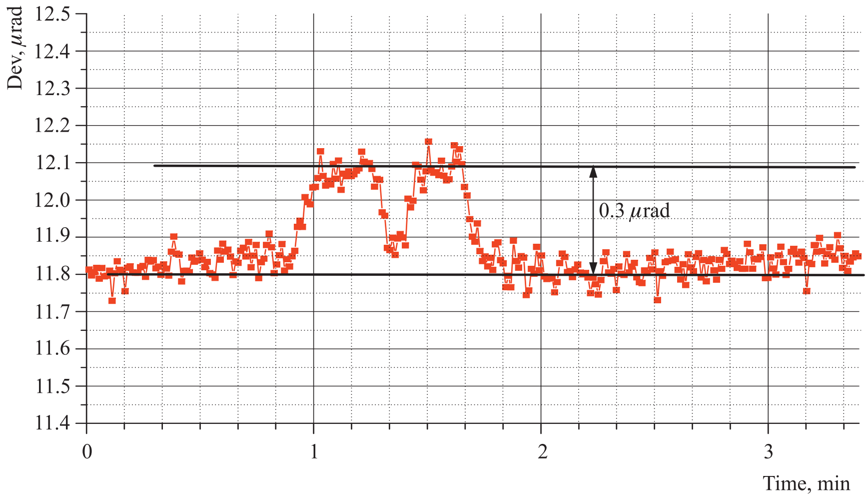

Fig. 7. Concrete floor inclination Dev (μrad) due to man presence in 3 m distance from the experimental set-up

Figure 5 shows the measurement data obtained for the 11:00–13:30 interval. The dinner time AB period demonstrates significant noise reduction. The Dev variation interval for AB period is about $4 \cdot 10^{-8}$ rad, which proves the noise industrial origin; the Dev variation interval for the working hours (period CD) was $1.7 \cdot 10^{-7}$ rad (Fig. 6).

Figure 7 demonstrates the concrete floor surface deforming: the angular reply Dev due to man double appearance close to the experimental set-up used. The measurements were made in the morning time. The registered tilt angle was 0.3 μrad.

3. THE MICROSEISMIC PEAK OBSERVATION BY GROUND ANGULAR MOTION

The ground periodical 0.1–0.7 Hz vertical oscillations are the known phenomenon [1–3] called "microseismic peak". We report here the first direct observation of this peak new feature as the *Earth's surface angular motion*.

This observation proves the significant possibility of the new high-resolution detector. With the help of the modified sensor (of 3 mm liquid depth), it became possible to find the Earth's surface nearly periodic inclinations Dev (μrad) of $\approx 5 \cdot 10^{-8}$ rad amplitude and period of ≈ 7.5 s corresponding to 0.13 Hz frequency (Fig. 8).

In Fig. 9 the Fourier analysis of observed signal is presented.

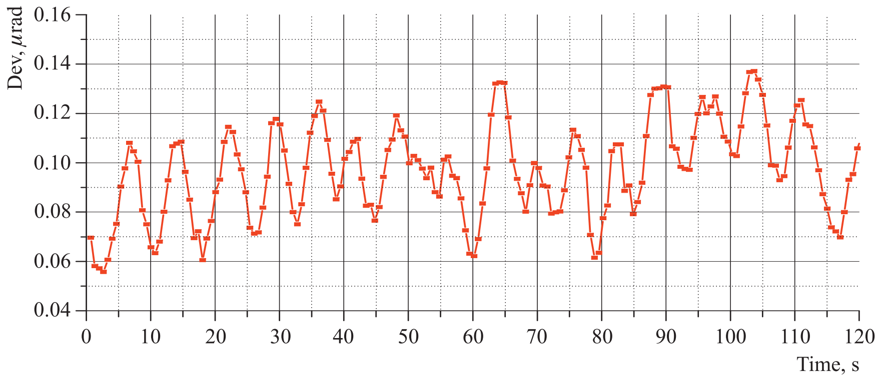

Fig. 8. The seismogram of the Earth's surface angular oscillation at the "microseismic peak" frequency

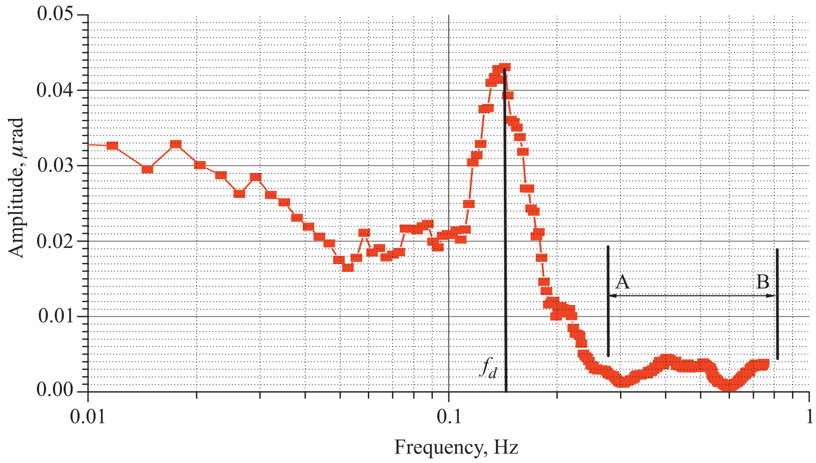

Fig. 9. The Fourier analysis of the Fig. 8 data

The Earth's surface oscillation at the "microseismic peak" frequency has the known source — the standing acoustic wave appearance between the ocean bottom and open water surface [1–4]. This standing wave origin is the composition of ocean tempests, of the Earth's crust movements, etc. Assuming $\Delta h = 0.5{-}4$ km interval for the ocean depth, $V = 1.4$ km/s for sound wave propagation in water, one obtains the frequency interval $\Delta\nu$ estimate for the main mode of the ocean water column oscillations $\Delta\nu = (1/4)(V/\Delta h) \cong 0.1{-}0.7$ Hz. This estimate practically coincides with the experimentally obtained width of frequency distribution in a microseismic peak (Fig. 9).

Generalizing one may suppose that the full pictures of the Earth's surface angular movement is expectedly a result of interference of surface ground waves started from an ocean side and propagating over the main land being surrounded by an ocean.

If so and with experimental periodicity of the microseismic peak, the Earth's surface might be covered by the standing waves and it is of significant practical interest to estimate the dimensions of the cells created by the standing waves. The observed event (Figs. 8 and 9) is then treated as the full picture "single representative". And it was obtained in *one observation point* (geographically) of this experiment. With known oscillation frequency interval $\Delta\nu = 0.1-0.7$ Hz and velocity $V' = 3.5$ km/s of wave propagation on the Earth's surface and using for the cell size $d = V'/2f$, one obtains 2.5–18 km for the size of the cells organized by the standing waves; here f is the frequency from $\Delta\nu$.

The Fig. 9 data allow one to estimate the inclinometer measurement precision. As seen from Fig. 9, the oscillation amplitude in the neighboring background frequency interval AB is about an order of magnitude smaller than the amplitude of the dominating frequency f_d of the microseismic peak.

Therefore, with the average $\approx 5 \cdot 10^{-8}$ rad (in Fig. 9) amplitude microseismic frequency f_d and an order of magnitude smaller background amplitude $\approx 5 \cdot 10^{-9}$ rad (AB interval, Fig. 9), one concludes that the background noise level in Fig. 8 is also $1 : 10$. In other words, the achieved inclinometer sensitivity estimate is on the level of $\approx 5 \cdot 10^{-9}$ rad.

4. SPACE LOCATION STABILITY OF THE LONG EXPERIMENTAL SET-UPS AND THE EARTH'S SURFACE ANGULAR OSCILLATIONS

It is known that in the colliders the beam profiles in the collision area do not always entirely overlap: some relative "wandering" of two beams cross-sections is observed. This phenomenon does not allow for beams profiles to coincide better than within 2 μm area spot [8–13].

One of the possible reasons for beams wandering is directly connected to the microseismic angular oscillations (Fig. 10).

And indeed, as was shown above, one observes nearly periodic Earth's surface angular oscillations with the microseismic peak frequency of 0.1–0.7 Hz and inclination angle amplitude of $\theta_{mp} = 5 \cdot 10^{-8}$ rad (Fig. 7) with the characteristic 2.5–18 km space period.

As seen from Fig. 10, different accelerator parts are inclined relative to the "basic" horizontal line and consequently particle beams going through the focusing elements leave them with some angular spread relative to the nominal.

It results in the known effect of the "lateral focus" which means the focus displacement δ_0 aside of nominal line. With the F as lens focus $\delta_0 = \theta_{mp} \cdot F$.

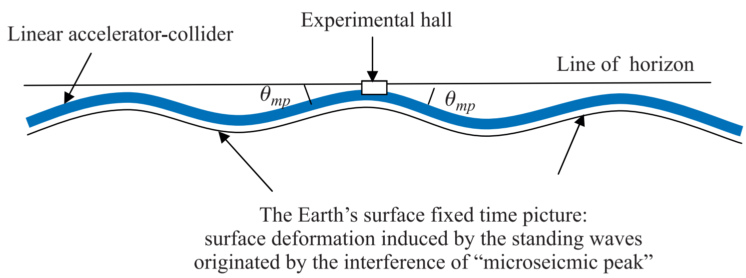

Fig. 10. The accelerator-collider positioning on the Earth's surface deformed by the microseismic peak wave

For the typical value of $F = 50$ m the estimate of the focus displacement is $\delta_0 = 2.5$ μm; it agrees with observable δ_0 values of the existing accelerators/colliders [7–12].

If one measures the Earth's surface space location under the accelerator with 10^{-9} rad precision and if one uses feedback system in loop with steering magnet in final focus area, it seems possible to take into account the microseismic peak noise influence on the accelerator and stabilize the beams focuses jitter within 50 nm.

CONCLUSION

The ground motion was studied by the detection of the Earth's surface angular oscillation. Instrumentally the method is based on the laser inclinometer of a conceptually new design using the reflecting surface liquid as a space stable (horizontal) reference level. The achieved inclinometer measurement precision was experimentally proved to be $\approx 5 \cdot 10^{-9}$ rad.

The achieved laser inclinometer sensitivity was proved by observation (in Geneva) of:

— Ground 2 μrad oscillation caused by the Siberian earthquake (6160 km);

— Single 1–2 μrad oscillation of origin to be studied;

— Industrial-origin noise of about 10^{-7} rad amplitude;

— Microseismic peak recognized for the first time as a ground $\approx 10^{-8}$ rad angular oscillation at 0.13 Hz frequency.

The last observed effect, if properly "compensated" by adequate instrumental method, could give significant colliders luminosity increase by reducing the beams intersection area to about 50 μm level (an estimate) due to some suppression of the lateral focus effect.

The instrument of this sort may happen to be useful for modern high-precision research equipment stabilization, for example, of large telescope to reach an extreme resolution with them.

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