THE DYNAMIC FAILURE MECHANISM OF COAL AND GAS OUTBURSTS AND RESPONSE MECHANISM OF SUPPORT STRUCTURE

by

Mingzhong GAO [a], Sheng ZHANG [b*], Jie LI [b], and Haiyun WANG [c]

[a] Institute of Deep Earth Sciences and Green Energy, Shenzhen University, Shenzhen, China
[b] School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan, China
[c] Tibet Development Investment Group Co., LTD, Tibet Lhasa, China

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In view of the common mine disasters such as coal and gas outburst caused by the destruction of gas and coal, the numerical model of RFPA-GAS software was used to establish a numerical model based on a gas outburst accident took place in return roadway of working face 15-17-16041 in Pingdingshan mine. The dynamic failure mechanism of coal and gas outburst under the conditions of different support strengths protection and unsupported conditions was analyzed. Four dynamic processes of coal and gas outburst were discussed, and the dynamic failure mechanism of coal and gas outburst was revealed. The results show that the outstanding effect of the roadway without support treatment is similar to that of the field, and the coal and gas outburst is obviously weakened for supported roadway. Which has effective control of the active support for the protrusion. When the support method is designed, the response mechanism of the coupled support structure should be considered. It provides some theoretical support for the gas outburst control.

Key words: *coal and gas outburst, numerical simulation, gas control, dynamic failure mechanism, support structure*

Introduction

At present, the energy structure of the world is dominated by fossil fuels, and fossil energy for a long period of time is still human survival and development of energy base [1, 2]. The world's total energy consumption is about 13.4 billionns of standard coal, of which oil, natural gas, coal and other fossil energy accounted for 85% over the next 20 years, coal is still the main fuel for electricity production, global demand will be 1.5% The speed of growth [3-5]. China is the world's largest coal-producing country, coal production accounts for about 50% of world production, as China's main energy, coal has become an indispensable part of our people's daily lives [6-8]. With the increase in coal mining depth and demand, mine gas management has become a major problem [9-11]. Although scientists increase gas control efforts to make gas accidents to ease, the problems facing gas governance is still grim.

At present, most of gas control before the first mining, is a passive way of governance. Once the occurrence of coal and gas outburst accident, it will inevitably cause damage [12-14]. There is little need for an active means to improve this passive situation, as there is

* Corresponding author, e-mail: zsroy2002@163.com

little protection system under the guidance of the theory of prevention and control of gas outbursts. Damage caused by gas containing coal and coal is the most common mine disaster in coal mine production [12, 13]. The main reason is due to mining caused by stress concentration, the load exceeds the strength limit of coal and rock, resulting in shear damage [14-16]. Combined with the role of the original coal gas pressure, the coal, rock and gas to the mined-out area is a typical dynamic phenomenon, the magnitude of the explosion according to the different conditions can be different orders of magnitude [17, 18]. How to protect, ahead of coal and gas out of the support measures is particularly important.

In order to ensure the normal production and personnel safety of coal mine, the coal and gas outburst examples are discussed. At the same time, the RFPA-GAS software is used to simulate the outstanding roadway. Based on the coupling model [19-22], the influence of different support strength on the outstanding effect is analyzed. It is well proved that this active method of support is effective for the prominent control, it is hoped to provide some help for gas control research in the future.

Analysis of coal and gas outbursts

The planning coal seam in a coal mine are hexyl group, and heptyl group, including $hexyl_{14}$, $hexyl_{15}$, $hexyl_{16\text{-}17}$, and $heptyl_{20}$ four layers of coal. $Hexyl_{15}$ coal seam is located at middle and lower part of Shanxi formation, the thickness of coal seam is 0.8 ~ 5.50 m, the average thickness is 3.40 m, the average thickness is 3 ~ 3.70 m, structure is simple, it is medium thick coal seam, coefficient of variation of coal thickness 10.3% ~ 23.6%, the recoverable index was 1, is commercial seam. Indirect roof for the light gray, gray fine, medium grain sandstone, the average thickness is 6.00 m, it is a hole area development. The upper coal seam is $Amyl_{9\text{-}10}$ 170 m apart from the coal seam, and the coal seam is 0 ~ 13.72 m below the $hexyl_{16\text{-}17}$ coal seam, which is generally from 3-7 m.

There are three large folded structures in the mine and three large and medium faults (drop ≥20 m), see tabs. 1 and 2 for details. The gas occurrence in coal mine seam is obviously affected by geological structure and top and bottom slates. The roof and floor of the coal seam are composed of gray siltstone, medium sandstone and gray sandy mudstone. The density is hard and the lithology is not conducive to the discharge of gas, storage conditions [23-26].

Table 1. The main folded structure within a mine field scope

Name	Location	Feature
Li mouth syncline	The north of shaft area	Axis upright, to the northwest tilt of the wide fold
Niuzhuang syncline	The south of shaft area, Niuzhuang～East workers town line	Axis upright, hub to the northwest tilt of the wide fold
Guozhuang anticline	The middle part of shaft area	Axis upright, hub tilted northwest

Table 2. The main faults of coal mine

Fault number	Fault name	Property	Trend [°]	Inclination [°]	Dip angle [°]	Fall head [m]	Control level
F1	Niuzhuang reversed fault	inverse	100	10	60	0 ~ 20	reliable
F2	F2 reversed fault	inverse	300 ~ 330	30 ~ 60	56	10 ~ 30	reliable
F3	The reversed fault of the original eleven coal mine	inverse	330	60	40 ~ 70	10 ~ 30	reliable

In order to learn from the lessons of the previous emergencies, we chose one of the more typical cases of outstanding accidents from 27 outburst accidents in a mine, that is, 1991.1.22, hexyl$_{15-17}$-16041 wind outburst accident.

The coal and its outbursts site

The total length of the design of the hexyl$_{15-17}$-16041 wind road is 1300 m, the excavation fault is 11.4 m^2, the net cross-section is 9.92 m^2, the average coal is 6 m thick, and the coal seam is inclined at 5°~7°. The top and bottom rock are mudstone or sandy mudstone, using Double T-steel metal trapezoidal support for support.

The head of the road surface elevation of – 270 m, about 370 m deep, with two 28 kW of the fan for the wind, the normal air-flow of 279 m^3/min, head of the normal gas concentration is of 0.2-0.6%, return air concentration is of 0.3-0.98%, the distance from the waterway to outburst location is 727 m, from the two small Kawaguchi 356 m.

Characteristics of coal and outburst process and outburst accident

January 22 zero schedule, the expected peak gas burst at the maximum speed of 1.2 L/min, in front of 1.7~2 m in front of the floor rock mudstone encountered in the road above the drill ahead of the time, hit 10 m when the sound of a gun. The 22 o'clock class, Xu Xiushan, the gas inspector, checked the gas for the first time, the gas for a concentration of 0.2%, 12 o'clock, second time to the head to check the gas concentration, head of 0.6%, other information is normal. Ventilated two comrades about 10:30 to the head of the inspection, coal and gas situation is normal. Zero point into the three sheds (107, 108, and 109), in front of a shed from the (700 mm) empty top distance, 12:55 in the clear coal, suddenly in front of the head sounded a caster, sound like a muffled mine, heard the guns, the workers run out, and then rang a gun again, took place coal and gas prominent.

Through field investigation and calculation, it is indicated that the formation of the hole was small outside the small wedge, from the head thrown 10.5 m, from 100 to all buried in the external 32° angle accumulation, the farthest to 94. Head left to help the first three shed legs bent, highlight the amount of coal 91 tonne, gushing out the amount of gas 4284 m^3. Outburst holes and coal accumulation are shown in fig. 1.

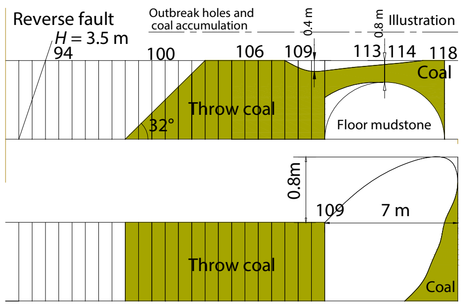

Figure 1. Outburst holes and coal accumulation of coal

Analysis of coal and its outburst cause

Through the comprehensive analysis of the prominent locations, the main reasons for this are:

- In the event of geological structure, ground drum, is the main factor that causes the protrusion, the bottom drum makes the local coal seam thinner, local coal seam thickening, changed the coal seam gas conditions. In addition the protruding point near the drop of 3.5 m reversed fault is a closed fault, resulting in prominent near the point of large gas production, high gas content. The 16041 wind tunnel left side of the section shown in fig. 2.
- The hexyl$_{15-17}$ coal seam roof and floor lit hology, dense mudstone and sandy mudstone, poor air permeability. In addition, the support strength of the roadway is not enough, resulting

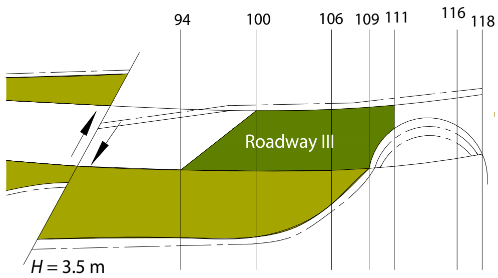

Figure 2. The 16041 wind tunnel left side of the section

in the overall strength of the surrounding rock support body is low, for the coal roadway in the provision of gas outburst conditions.

– The protruding point has just entered the prominent area of the mining area, highlighting the point from the F2 inverse fault 14.5 m. The structures in this area are mostly pressure or torsional structures, which are a good place for the occurrence of gas, creating the conditions for coal and gas outbursts.

– The outburst point is at the edge of the pillar of the mountain coal pillar in the mining area, projection the coal is just at the edge, the section of the crustal stress, stress is more concentrated.

– High-level coal seam damage is more serious, is a class III, strong damage to coal, coupled with the prominent front of the geological structure encountered, ahead of the number of less drilling (three), making the road ahead of the gas cannot be successfully released, for one reason.

Simulation of dynamic response mechanism of support structures and gas outbursts

Establishing a numerical model

According to the geological characteristics of the existing$_{15\text{-}17}$-16041 air way, a numerical model has been established to mainly analyze the influence of supporting intensity under certain tectonic influence on gas outbursts. The A3.5-meter reversed fault is set up, and the thickness of the upper and lower coal inventory is 6 m averagely. The model adopts the plane strain analysis and the model size is 40 m × 60 m. It is divided into 160 × 240 cells. The original gas pressure of coal bed is 2.1 MPa. The upper part is stress boundary, simulated as 10MPa, which is equivalent to the buried depth of about 500 m. The lower parts of the left and right are constraint conditions. The numerical model is shown in fig. 3, and the mechanical and seepage parameters of the coal strata in the numerical model are shown in tab. 3.

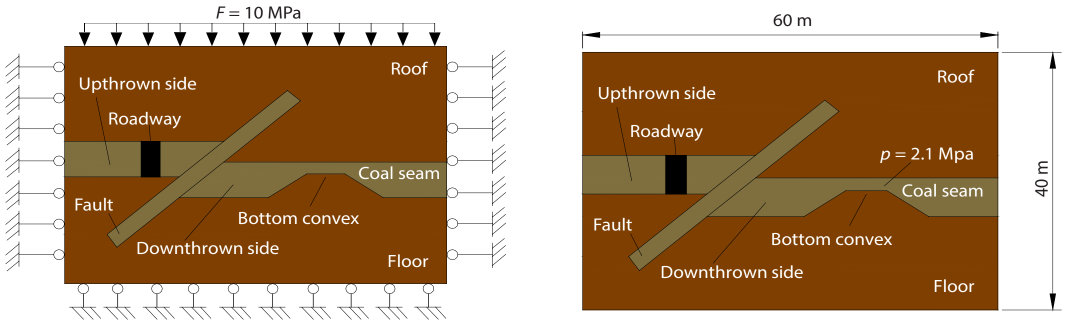

Figure 3. Mechanical and seepage model of coal and gas outburst

Table 3. Assignment parameters of numerical model

Position	Homogeneity	Modulus of elasticity [GPa]	Compressive strength	Poisson ratio	Permeability coefficient	Gas content coefficient	Pore pressure coefficient	Coupling coefficient
Coal bed	2	5	5	0.35	0.01	3	0.6	0.2
Roof and floor	10	20	300	0.25	0.0001	0.01	0.01	0.1

Analysis of simulation results

Coal and gas outburst in the case of no support

In the simulation, coal and gas outbursts occur during the advance from ascending fault wall to descending fault wall. Figure 4 shows the corresponding shearing stress field distribution from ascending fault wall to descending fault wall in the case of no support, in the fig. 4, the gray level shows the magnitude of the stress: the greater the gray level, the greater the stress. The numerical simulation results can clearly show that there is no outburst in the advance of ascending fault wall of the coal bed but there are outbursts in the advance from ascending fault wall to descending fault wall. The advance and outbursts can be divided into four stages: stress concentration stage, stress-gas inducing coal strata fracture stage, gas pressure-driven crack expansion stage, and throwing cataclastic coal strata stage. In fig. 4, *Step No. 11-13* represents the stress concentration phase, *Step No. 14-16* represents the stress gas induced coal rock fracture phase, *Step No. 17-20* represents gas pressure-driven crack expansion stage, and *Step No. 21-27* represents throwing cataclastic coal strata stage. When the support is not made, a slight external bulge occurs at the working face when driving on the ascending fault wall of the coal bed. In the process of advancing from the ascending fault wall to the descending fault wall, the external bulge intensifies and the gas content in the working face is suddenly big and suddenly small. With the advance, under the action of crustal stress, the coal containing gas is damaged more seriously. Then, under the combined action of gas pressure and crustal stress, the damaged coal is stripped continuously and the protrusions extend to the deep. At the same time, gas storm is formed in the protrusions to carry away the stripped broken coal, and after being crushed, it is thrown to the goaf.

Coal and gas outbursts in the case of support

The tunnel is supported by grouting and cable anchor to change the strength of surrounding rock of the support. The strengths of surrounding rock of the support after being supported are 5 MPa and 10 MPa, and the simulation results are shown in figs. 5 and 6. Figure 5

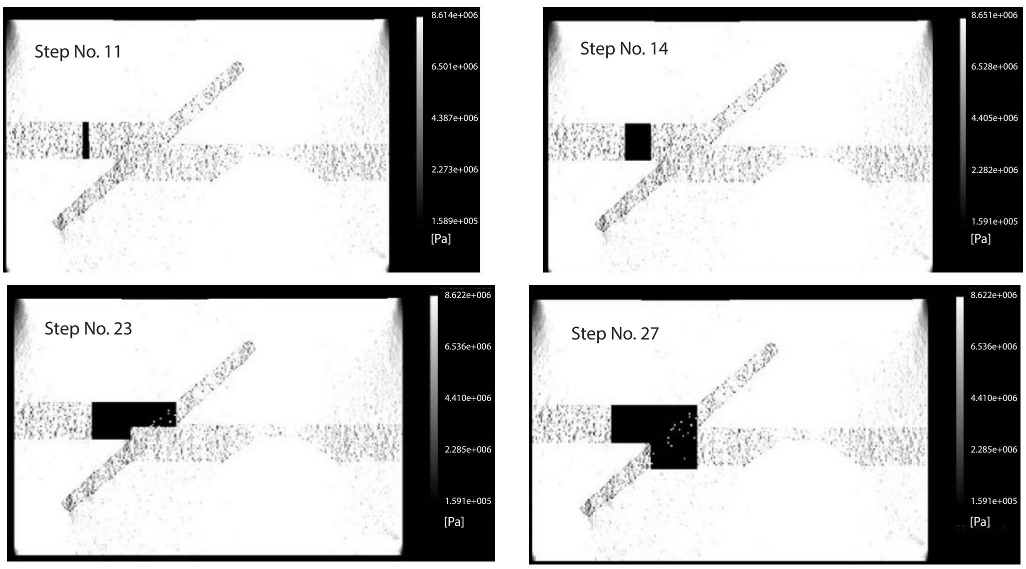

Figure 4. Coal and gas outbursts in the case of no support

shows the simulation result chart in the case of 5 MPa of supporting strength, and fig. 6 shows the simulation result chart in the case of 10 MPa of supporting strength. The numerical analysis is conducted for the simulation results, obtaining curve charts of coal internal stress and gas of heading faces before and after the supporting, respectively, as shown in figs. 7 and 8. Compared with the condition of no support, the slight external bulge occurs in the advance from the ascending fault wall to the descending fault wall in the coal roadway after being supported, and the gas content in the working face increases slightly. With the continuous advance, the external bulge becomes obvious, the gas content fluctuates, and a small amount of broken coal

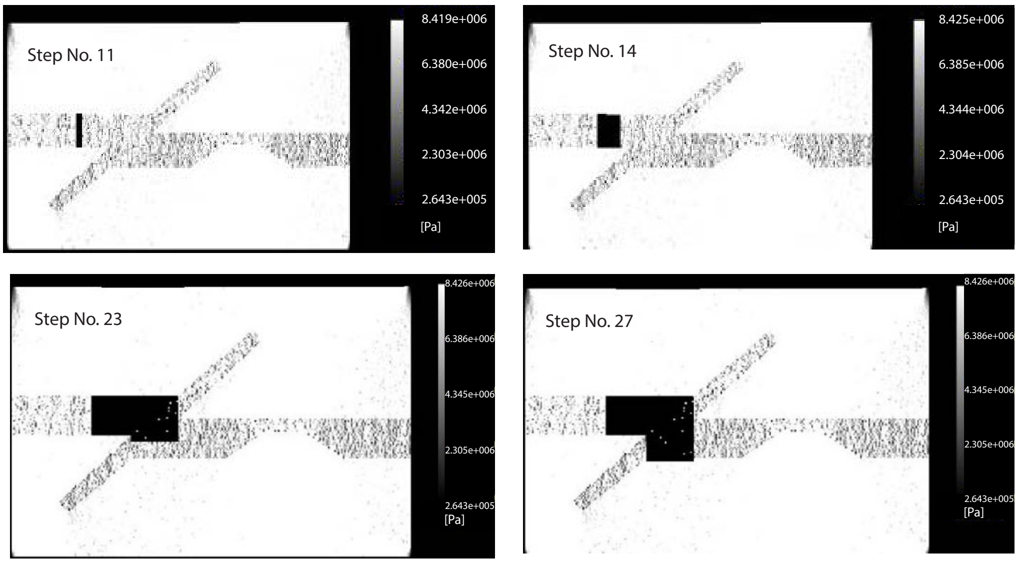

Figure 5. Coal and gas outbursts when the supporting strength is 5 MPa

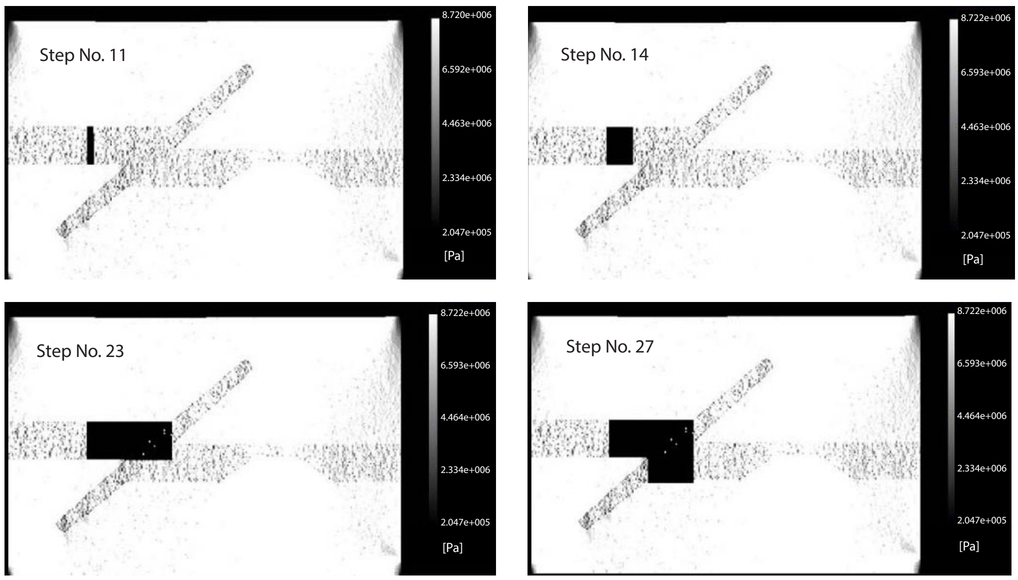

Figure 6. Coal and gas outbursts when the supporting strength is 10 MPa

is thrown into the goaf with the gas storm. In the process of coal bed excavation, the bulging phenomenon- and the amount of emitted cataclastic coal in the excavation face decreases with the increase of supporting strength.

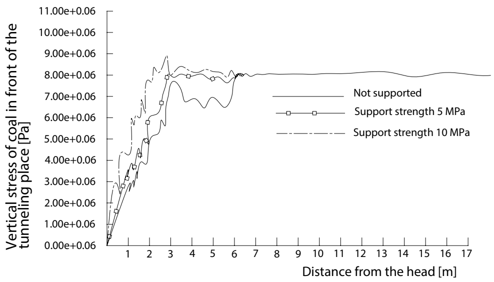

Figure 7. Curve chart of coal internals tress in front of heading faces

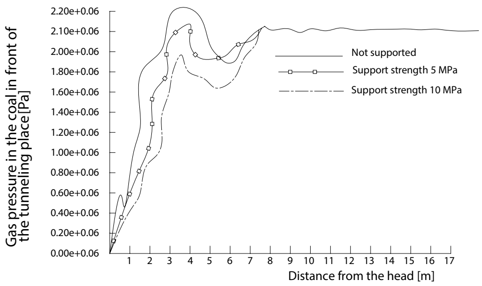

Figure 8. Curve chart of gas pressure in front of heading faces

Analysis of dynamic protection mechanism of coal and gas outbursts

Stress variation in the process of outburst

– Stress concentration stage

During the excavation of the coal bed from the first step to the third step, the coal bed is slightly damaged under the action of stress. The fault is far from the working face and remains in the state of original rock stress almost without any damage. With the excavation in the second step, the range of disturbance increases, and the extent of damaged coal rock increases under the action of stress.

– Stress-gas inducing coal strata fracture stage

During the excavation of the coal bed from the fourth step to the sixth step, the extent of damaged coal rock increases under the action of stress. The stress concentration occurs near the fault. The coal and fault fracture thread together with gas released from coal.

– Gas pressure-driven crack expansion stage

During the excavation from the seventh to the tenth step, the fault is exposed. Under the action of the concentrated stress and gas pressure, the cracks are gradually expanded, and the more fractured coal rock is thrown out first.

– Throwing cataclastic coal strata stage

During the excavation from the eleventh step to the seventeenth step, with the expansion of cracks, the coal rock becomes more broken and loses the carrying capacity. Since the coal bed in front of the convex bottom of descending fault wall is still in high gas pressure, gas is ejected from the cracks with broken coal rock of no carrying capacity thrown to the goaf.

Analysis of dynamic protection mechanism

Grouting and cable anchor are used to support the tunnel. Some of the solidified slurry is injected into the cracks and pores of the coal rock. The slurry is solidified to improve its physical and mechanical properties, reduce its permeability and increase its homogeneity. Cable anchor is used to strengthen the friction between the joint surface and rock and then enhance the stability of rock blocks and strata. The comprehensive effect can reduce the influence of the stress concentration and the original gas pressure of coal bed during the excavation process of coal bed in order to weaken or even eliminate the outbursts.

Conclusions

Using RFPA-GAS numerical simulation software and the outbursts in the existing$_{15\text{-}17}$-16041 air way of a coal mine, the numerical simulation is conducted. Simulation results are shown in fig. 4. The outburst effects are similar to the outbursts on the spot, so this model can be used to reflect the actual situation of outbursts on the spot. After the model parameters are changed, the situations in the case of 5 MPa, as shown in fig. 5, and 10 MPa, as shown in fig. 6, of the surrounding rock strength after being supported are simulated. It can be clearly seen that the coal and gas out bursts are obviously weakened, and the main conclusions are:

- The outbursts occur in the advance from the ascending fault wall to the descending fault wall. The outbursts occur after the fault is exposed and a large amount of gas is accumulated in front of the convex bottom. The fractured coal is thrown into the goaf under the action of high gas pressure and crustal stress.
- The enhancement of supporting strength in the tunnel has a positive effect on the gas control of coal mine. The active support can obviously reduce or even effectively inhibit the occurrence of outbursts.

In the existing production process, on the one hand, we should detect the fault well; on the other hand, in the stress and gas concentration areas, priority should be given to the use of grouting and cable anchor support to prevent the occurrence of coal and gas outbursts.

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