

Point and Line Attractors Emerging in the System Including the Interaction among Heat, Fluid Pressure and Dilatancy

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We show two geometrically different attractors, point and line attractors, emerge within the framework including the interaction among heat, fluid pressure and dilatancy associated with dynamic earthquake source process. To show that, we consider qualitative behavior of the solution orbit in the ϕ - v space, where ϕ and v describe the inelastic porosity and the slip velocity, respectively. We first consider nullclines, which are obtained by the conditions $\dot{v}=0$ and $\dot{\phi}=0$. For $\dot{v}=0$, the straight line $v=0$ and the curve $v=1-\beta g(\phi)$ are nullclines, where $g(\phi)$ is the function describing the porosity evolution law and β is a positive constant number. The curve $v=1-\beta g(\phi)$ on the ϕ - v space will be referred to as C^{crit} henceforth. For $\dot{\phi}=0$, the straight line $v=0$ and the curve $\phi=1$ are found to be nullclines. Clearly, the line $v=0$ is the common nullcline for both equations.

We simply assume that C^{crit} crosses the ϕ -axis once, and C^{crit} is ascending with increasing ϕ . We consider a solution orbit crossing the v -axis in the region $0 < v_0 < 1$, where v_0 is the slip velocity at $\phi=0$, since v and ϕ are normalized and take values between zero and unity. It should be noted that the orbit is not horizontal nor vertical at the point crossing the line $v=0$, even though the line is a nullcline. This occurs because $v=0$ is a nullcline for both equations; both the relationships $\dot{v}=\dot{\phi}=0$ are satisfied on the line $v=0$, which enables $dv/d\phi$ to be nonzero there. Moreover, we can confirm the orbit connects the points $(0, v_0)$ and $(1, 1)$.

The solution orbits and the moving direction of the solution conclude that we have attractor and repeller on the ϕ -axis; $\{(\phi_a, 0) \mid 0 \leq \phi_a \leq \phi_c\}$ is an attractor, while $\{(\phi_r, 0) \mid \phi_c \leq \phi_r \leq 1\}$ is a repeller, where ϕ_a and ϕ_r are the real numbers satisfying $\phi_a < \phi_c$ and $\phi_r > \phi_c$, and ϕ_c is the ϕ value of the point where C^{crit} and ϕ -axis cross. In particular, note that ϕ_a and ϕ_r take continuous values. These non-isolated fixed points appear because the line $v=0$ is a nullcline for both equations, and this is characteristic behavior of the present system. In addition, the point $(1, 1)$ is also the attractor because C^{crit} and all orbits are absorbed into the point $(1, 1)$. We can therefore summarize that the attractors are categorized into two geometrically different groups: they are given by the line $\{(\phi_a, 0) \mid 0 \leq \phi_a \leq \phi_c\}$ or the point $(1, 1)$. The detail of $g(\phi)$ does not affect the emergence of the attractors.

キーワード：熱、流体圧、空隙生成、解軌道、アトラクタ、リペラー

Keywords: heat, fluid pressure, dilatancy, solution orbit, attractor, repeller