Comments on the manuscript "Numerical Investigation of Parameters Influencing Back-Thrust Development in Outer Wedge Fronts of Fold-and-Thrust-Belt Systems. " by Saeed Mahmoodpour et al.

General comments

The article presents a numerical approach that aims to identify the parameters and boundary conditions for which the development of back-thrusts predominates in fold-and-thrust belt systems. The authors performed simulations for 36 different prototypes. The prototype comprises six layers, including three for the basement and one for surface deposition. The parameters tested are the strength of the material, the friction value on the basal décollement, the dip of the basal décollement and the displacements imposed for the calculation. The authors show that back thrusts occur when the bulk material is resistant and friction on the basal décollement is low.

Globally, this article is rather well written but English is not my first language. Therefore, I will not comment on the language used.
The origin and mechanical cause of the vergence change in the fold-and-thrust belts remain poorly studied. Consequently, the question of this study is very interesting. Furthermore, the use of numerical modelling enables the examination of numerous models, thereby facilitating the elucidation of the pertinent question. Some studies have been carried out in sandboxes. Gutscher et al (2001) highlighted the development of BT. However, they show a single sandbox experiment with the backward vergence. The findings of the backward vergence are also outlined in the paper by Zhou and Zhou (2021) and they indicate that this vergence alteration is attributable to the lateral/basal shear stress ratio. Nevertheless, in the context of sandbox utilization, it remains uncertain whether this constitutes an experimental bias. This issue is not present in the simulations presented in this article, as they are two-dimensional numerical simulations.

I will first give my main remarks and then comment by section.

My main concerns are that:
(1) *Definition of Back-Thrusts:* while the figures presented is readily comprehensible, discerning the distinctions between each case tested is challenging. However, what do you really mean by 'Back-Thrust (BT)'? Is it a vergence towards the rear of the wedge with a succession of faults that chronologically develop towards the back wall – as landward sequence? Or is it a main ramp associated with several BTs, as can be seen in sandboxes? These BTs are concomitant with ramps or they are out of sequence? I don't think it's clear from the figures in the article where the BTs you want to show are located. In general, it is advisable to indicate the location of faults by placing arrows on each figure. Moreover, it would be beneficial to present the results in a more concise manner, or to provide guidance to the reader regarding the specific details that should be observed in order to facilitate comparison between each case.
In the introduction, the authors cite the works of Cubas et al (2016) and MacKay (1995) with regard to the orientation of the stress direction relative to the décollement. This aspect was previously demonstrated in studies conducted prior to the publication of these articles. Cubas et al (2016) demonstrated that a significant friction contrast between the décollement and the bulk material of the wedge is necessary for the formation of landward sequence. This is also demonstrated in this present study. But Cubas et al (2016) add that the wedge must be to get very close to the upper limit of the Dahlen envelope (1984), implied a steep surface slope. In this case, the major fault that develops in the wedge is a BT, with an associated fore-thrust. If the slope is really too steep, gravity slides will be observed at the rear of the wedge.
I think that in the present study it would be judicious to show a result with a strong sedimentation of surface in order to increase the slope of surface of the wedge, with a strong material strength of the bulk and a very weak friction at the base of the wedge. Perhaps it has already been calculated among the 36 cases, but if so, I haven't found it.

(2) *Mechanical criterion:* in addition, to make it easier to read, it would be advisable to explain the mechanical behavior law used a little more explicitly: the SR3 yield surface. Why p and q do not appear in the equation 4? What exactly does represent the parameter β in the equation 4? Usually, β is used for the basal dip in the Wedge Theory. Why is β so strong (Table 2)?
What do you mean when you mention the strength of material? Is it in terms of cohesion or just pre-consolidation?
Finally, in table 2, are we to understand that there are specific parameters for layers 4 and 5 and that all the other layers have the same parameters?
(3) *Plastic strain criterion:* what criteria did you use to categorize the results? You mention a critical value of 20 (line 125). What does this mean? You also mention a mesh size with an associated plastic deformation value (lines 127-130). Could you explain this part?
Finally, how is the porosity calculated?
(4) *Input parameters:* you need to check the parameters. I think there's some confusion between β and α. The parameter α is commonly used for the surface dip and β for the basal décollement dip. It would be simpler to use this nomenclature to make it easier to read. On the figure 1, α is noted at the base of the layer 4… and as I pointed out above, β is used for a friction parameter. It's confusing.
Concerning boundary conditions in displacement, I understand that for most models you require a pure displacement of the back wall. And for some (*) you also require the base to be able to move. What conclusions do you draw about the development of back-trusts linked to this specific displacement condition? How do you explain this difference of boundary conditions in nature?
(5) *Initial prototype and activation of the décollement:* do the top of layer 3 and the base of layer 2 have the same dip? Why are there three layers in the basement with different rheological parameters (according to table 2)?
According to the diagram on the Figure 1, the décollement can only be activated up to the black cross. Would it be possible to indicate with a line on each result figure which part of the décollement is actually activated? In most of the results presented, the décollement seems to have reached the plastic limit right up to the front of the wedge at 2 Ma. Then the plasticity in this basal layer seems to change over time. What we don't know is whether décollement is activated beyond the root of the fault formed, which is possible if the wedge is in a critical state in the Dahlen sense.
(6) *References:* The authors provide a comprehensive introduction, which encompasses both the numerical modelling articles and the results of the analogue sandbox modelling. However, it seems pertinent to highlight the contributions based on the Limit Analysis Theory applied to fold-and-thrust belts. In particular, Mary et al. (2013) have demonstrated that the location of faults and their lifetimes are based on deterministic chaos. The work by Adwan et al (2024), which has recently been published in Solid Earth EGU, will enable the authors to compare their results in terms of stress values. Finally, Robert et al (2019) have investigated the impact of syn-tectonic sedimentation on the stresses in a ramp propagation fold. These works can be used as a basis for discussion or can be cited in the introduction.

In the following sections, I will give comments and suggestions to particular points in the text. Numbers are line numbers. I hope my comments are useful and constructive.
Best regards,
Pauline Souloumiac.

Section comment

Section 2.1:
127 - 130: Please, clarify these criteria.

Section 2.2:
141: the values of the parameters written in this way are not clear. present them in the form of a list.
In this section, you should quote Figure 1 for a better understanding of the geometry.

Section 2.3:
204: I don’t understand the meaning of the parameter n_{sr3}.

Section 2.4:
231: This word “coefficient” is missing.

Section 3.1:
267: What criteria do you use to describe an effective thrust? This ties in with my general comments on mechanical criterion.

Section 3.3:
348 - 355: it is challenging for the reader to ascertain the outcomes, as they are not explicitly in the primary text.

Section 4.1:
374-379: This part is not clear to me. I don't understand why the layer deposited during the folding sequence has to be pre-consolidated. Is this specifically due to the choice of SR3 yield surface criterion?

391: If the ramp develops at the rear of the structure, I think that's explained by the Coulomb critical wedge theory: the wedge is unstable at the start of the folding sequence.

Section 4.2:
422: add unit “degrees” for the dip angle.

Section 4.4:
465: replace “taper strength” by “bulk strength”.

Table 1:
Replace “β in Eq.2” by “β in Eq.4”.

Table 2:
Check the name of the dip of the décollement

Figure 4:
Do you consider that the pop-up at the back of the wedge represents the BT?

Figure 6:
why there are two incipient pop-ups at 2Ma and a major ramp rooted from the right basal corner at 4Ma?

Figure 7:
d) How can you explain the high stress values at the surface of the model?

Figure 8:
Why does the décollement appear to be fully activated at 2 Ma? Whereas this is no longer the case at 4 Ma. Or maybe the layer underneath was completely plastic and then it wasn't?

Suggested additional references:

Mary, B. C. L., Maillot, B., & Leroy, Y. M. (2013). Deterministic chaos in frictional wedges revealed by convergence analysis. *International Journal for Numerical and Analytical Methods in Geomechanics*, *37*(17), 3036-3051.

Adwan, A., Maillot, B., Souloumiac, P., Barnes, C., Nussbaum, C., Rahn, M., & Van Stiphout, T. (2024). Understanding the stress field at the lateral termination of a thrust fold using generic geomechanical models and clustering methods. *Solid Earth*, *15*(12), 1445-1463.

Robert, R., Souloumiac, P., Robion, P., & David, C. (2019). Numerical simulation of deformation band occurrence and the associated stress field during the growth of a fault-propagation fold. *Geosciences*, *9*(6), 257.